THE INFLUENCE OF STRAINS AND DIETARY FATS ON FATTY ACID COMPOSITION OF EGG YOLK, ADIPOSE TISSUE AND OVA OF CHICKENS

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ABSTRACT

THE INFLUENCE OF STRAINS AND DIETARY FATS ON FATTY ACID COMPOSITION OF EGG YOLK, ADIPOSE TISSUE AND OVA OF CHICKENS

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An experiment was conducted to study the effects of strains and breeds of chickens and dietary fats on fatty acid composition of egg yolk, adipose tissue and immature ova. The effects on feed efficiency and egg production were also observed. A complete factorial design was used in which three ration treatments (low-fat, 14% soybean oil and 14% rapeseed oil) were fed to each of three strains of hen for six months.

In general, hens fed a high-fat ration ate less feed than hens fed a low-fat ration. The relative decrease in feed consumption was proportional to the energy density of the ration. Feeding soybean oil in the ration had little or no effect on the total quantity of eggs produced per hen day. However, hens fed the low-fat diet produced more eggs than hens fed the soybean oil diet, but the eggs were smaller in size. Feeding rapeseed oil (14%) depressed feed intake of hens, reduced feed efficiency, reduced egg production

and decreased egg size in comparison with feeding soybean oil. As the experiment progressed, feed efficiency and egg production decreased while yolk size and egg size increased on all ration treatments.

The inclusion of 14% soybean oil or rapeseed oil caused appreciable changes in the fatty acid composition of egg yolk, immature ova and adipose tissue. In comparison to the low-fat treatment, level of linoleic acid in the tissues increased markedly and that of linolenic acid moderately when soybean oil was fed. Increases in oleic and linolenic acids of tissues were accompanied by a decrease in oleic acid.

Strain and breed differences were noted for C_{16}, C_{18}, $C_{18:1}$, $C_{18:2}$ and $C_{22:1}$ contents of egg yolk, for C_{16}, $C_{18:1}$, $C_{18:3}$ and $C_{22:1}$ contents of adipose tissue and for C_{16}, C_{18}, $C_{18:2}$ and an unidentified fatty acid in ova. These differences among tissues of various strains suggests that the control of fatty acid composition in tissues may be polygenic in nature. Differences in fatty acid composition between Pearlettes and Shaver which had White Leghorn parentage, were less than differences between these two and Clarks which was entirely of meat origin.

All the fatty acids in developing ova, except an unidentified fatty acid, were altered significantly by the

dietary fats. However, the magnitude of effects of these dietary fats on fatty acid composition of developing ova were not as great as those observed in the case of mature egg yolk. The results of this study indicate that fatty acids in ova are probably derived selectively from adipose tissue during early development but, as the ova grow larger, they become more dependent on fatty acids of immediate dietary fat as it is assimilated and directed to the more actively and rapidly growing ova approaching maturity.

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INTRODUCTION

Fats are the richest source of dietary energy; intensive research on the use of fats for the purpose of providing dietary energy in poultry rations was stimulated by the surplus of fats in the world market during the past 15 years. Most of the research has been conducted to evaluate the use of various fat sources as ration ingredients to improve rate and efficiency of production of poultry meat and eggs. Recently, attention has been focused on determining the influence of dietary fats on the fatty acid composition of egg yolk and depot fat.

Considerable information has been gathered concerning the influence of dietary fat on the fatty acid composition of egg yolk and depot fat. However, little information is available about the variation which may exist due to genetic differences of chickens, with regard to fatty acid composition of egg fat and adipose tissue. In addition, little is known about the influence which genetic differences of birds may exert on the efficiency with which various dietary fatty acids are utilized.

It was the objective of this study to examine the variation in fatty acid composition due to genetic differences between and within three strains of hen, and to investigate

the influence of dietary fat on this respect in growing ova. An attempt was also made to obtain further information on the effects of dietary rapeseed oil and soybean oil on the fatty acid composition in mature egg and depot fat. The experiment was designed so that an evaluation could be made of any possible interactions between ration, strain and age (period), which may have modified the independent effects. In addition, observations on feed consumption, feed efficiency, egg production and size of eggs as related to strains and ration treatments were made.

REVIEW OF LITERATURE

The Synthesis or Interconversions of Polyunsaturated Fatty Acids in Hens

Synthesis and interconversion of fat is believed to occur in the animal body. However, only limited work has been done with polyunsaturated fatty acids in this respect. Reiser (1950a) fed hens a "fat-free diet" and observed changes in egg yolk fat. He found that the fatty acids possessing five and six double bond disappeared from the glyceride and phospholipid fractions of the yolk after four and eight weeks, respectively. The two, three and four double bond fatty acids decreased very slowly, until 16 to 25% of their control level was attained within 14 weeks after feeding. When four per cent cottonseed oil (representing the addition of linoleic acid) was added to the "fat-free diet", the six double bond acid in the yolk vanished at the same time as in the "fat-free diet", but fatty acids with three, four or five double bonds declined to a minimum after two weeks. The two double bonds acid remained unchanged. This illustrated that hens cannot synthesize three, four, five and six double bonds fatty acids from non-fat precursors, but can synthesize these fatty acids (except six double bonds acid) from oleic or

linoleic acids.

In growing chicks, it has been shown that the ingestion of linoleic acid resulted in the deposition of arachidonic acid and an unidentified fatty acid with five double bonds, but not linolenic acid in the adipose tissue; while the ingestion of linolenic acid resulted in the deposition of fatty acid with six double bonds (Reiser, 1950b). In a later study, Reiser (1951) presented evidence that in laying hens linoleic acid was not converted to linolenic or the six double bonds fatty acid, but that the addition of linoleic acid to the ration resulted in an increase in linoleic and arachidonic acids and an unidentified five double bonds fatty acid of egg yolk lipid. Supplementation of linolenic acid lead to the changes of all polyunsaturated fatty acids having two to six double bonds. Feeding linolenic acid to hens that had been fed a "fat-free ration" provided further evidence that a mechanism was present in the hen which rapidly converts linolenic acid to lesser and more highly unsaturated fatty acids. Neutral fat of egg yolk from hens fed a "fat-free diet" contained only about one per cent linolenic acid as compared to 14.4% in yolk of hens fed a stock ration which contained fat. Since this fatty acid was not supplied in the ration for over one year in the former case, it must have been synthe-

sized by the hens. Apparently, laying hens on a "fat-free ration" can synthesize a minimum amount of unsaturated fatty acids to meet their requirements.

Choudhury and Reiser (1959) included three levels of linoleic acid (0.55%, 7.5% or 15%) in a stock diet, and fed the ration to hens. They found that linolenic acid level of triglycerides in the yolk was not influenced by levels of dietary linoleic acid above 0.55%, except for a slight transient increase in linolenic acid when the 15% level of linoleic acid was fed. The authors felt that this temporary increase was probably due to the occurrence of an intermediate product in arachidonic acid synthesis, such as 6, 9, 12 octadecatrienoic. The constant concentration of linolenic acid in the egg yolk triglycerides substantiated the fact that linolenic acid is not produced from linoleic acid by the hens. When 0.55% or 7.5% linoleic acid was fed, linoleic acid content of the yolk increased from 10 to 30%, but no further increase was obtained when a higher level of linoleic acid was added to the ration. Following the ingestion of diets containing 7.5% linoleic acid, the arachidonic acid level of triglycerides initially changed from 0.5% to a maximum of two per cent and then dropped to the original level after five eggs were laid. This was attributed to the limited ability of hens to incorporate

dietary linoleic acid into yolk triglycerides, and also a homeostatic mechanism which controls the limits of polyunsaturated fatty acids deposited in the egg.

Fisher and Leveille (1957), working with hens fed a semi-synthetic diet containing corn oil, found a relatively low level of linolenic acid in egg yolk than that of linseed oil ration. He stated that hens cannot synthesize linolenic acid, but under practical situations obtain it from the residual oil in the soybean meal portion of a practical ration. Since in this experiment the hens were fed the semi-synthetic ration for only one week, they could have drawn the linoleic acid from depot fats for deposition in egg yolk fat.

Feigenbaum and Fisher (1959), in an attempt to establish the source of fatty acid in eggs from hens receiving a "fat-free diet", showed that since there were insufficient polyunsaturated fatty acids ingested to account for the amount deposited in the yolk, it was evident that the hens selectively drew upon their body fat for the production of egg fat. Under normal conditions, the polyunsaturated fatty acids are not synthesized and appear to be transferred directly from the diet.

Early investigations made by Cruickshank (1934) showed that hens on "fish meal-free" and hempseed oil

rations containing 2.3% and 29.5% ether extract, respectively, laid normal egg with respect to characteristic of the lipids. Conceivably, hens receiving a low-fat (fish meal-free) diet obtained a considerable proportion of the normal egg fat through biosynthesis from non-fat constituents of the feed rather than by direct assimilation of fats. However, if adequate dietary fats were supplied, the hens utilized ingested fat for direct deposition of egg fat.

The Influence of Dietary Fat on Egg Yolk Lipids

Ether extract of fresh yolk is about 30 to 32% of the total yolk weight and remains relatively constant. However, the various fat components of the total lipids, particularly phospholipids are variable (Mangold, 1931; Beare et al. 1961).

Weinman (1956) claimed that nearly all egg yolk lipids are bound to protein. Evans and Bendemer (1961) presented evidence that egg yolk contains two lipoprotein complexes, lipovitellin and lipovitellenin. They also showed that lipovitellin comprised 6.8% of total egg yolk lipids while lipovitellenin comprised 93.2%. Lipids of lipovitellin were mostly firmly bound, while those of lipovitellenin were loosely bound.

Privett et al. (1962) employed thin layer chroma-

tography for the analysis of the major egg yolk lipids, and found the following fractions: 5.2% cholesterol, 65.5% triglycerides, 28.3% phospholipids and traces of cholesteryl esters. Also, these workers separated egg yolk lipids into neutral lipids and phospholipids. The neutral lipids fraction was further fractionated by molecular distillation into triglycerides (64.2%) and a minor constituent fraction consisting of cholesterol. The phospholipids were fractionated by column chromatography into cephalin (4.7%), lecithin (22.9%) and a small amount of an unidentified fat component (3.5%). Similar information was also obtained by Chen et al. (1965).

The component fatty acids in egg yolk lipids were investigated by MacLean (1918) and Needham (1931). In general, the fatty acid composition of egg-lecithin was palmitic, 28.5%; stearic, 14%; oleic, 33%; and linoleic, 24%. Levene and Rolf (1922) and Hatakeyama (1930) reported the presence of polyunsaturated fatty acids; namely, arachidonic and linoleic acids. Grossfeld (1933) observed that egg fat contained 5.1% unsaponifiable material and 90.7% mixed fatty acids, in which the composition of fatty acids were as follows: stearic, 2.2%; palmitic, 32.4%; oleic, 44.2% and linoleic, 3.2%.

Cruickshank (1934) conducted a series of experi-

ments in which the effect of dietary fat on egg yolk was studied in detail. A high level (28%) of supplemental fats representing wide differences in fatty acid composition were used. She found that the iodine value of egg lipids from hens fed hempseed oil increased steadily from 84 to 127.2 within 16 days, and then remained constant. When highly saturated mutton fat was fed, there was little effect on the iodine value of yolk lipids. Increases in degree of unsaturation of yolk lipids were accompanied by decreases in percentage of saturated fatty acid of egg fat. When a hempseed oil diet possessing a high concentration of unsaturated fatty acids and protein was fed, the iodine value was highest, and the percentage of saturated fatty acids was lowest. In contrast, a high carbohydrate, hempseed oil ration resulted in a reduction of unsaturation, and a slight rise in the level of saturated fatty acids. She concluded that the degree of unsaturation and the proportion of the component fatty acids were modified by unsaturated fatty acids and that ingested saturated fatty acids had relatively little effect on the normal fatty acids composition of egg fat.

Riemenschneider *et al.* (1938) made a study of yolk lipids with hens fed two per cent cod liver oil and fish meal (high level of C_{22} unsaturated fatty acid). They

found that the fatty acid composition of egg yolk glycerides resembled that of the depot fat. Concurrently, the phospholipid contained a somewhat high level of saturated acid together with a considerable amount of C_{22} (clupanodonic) acid which only appeared in traces in the glycerides.

Fisher and Leveille (1957) reported that linseed oil produced a distinct increase in linolenic acid content of egg fat, whereas with soybean and safflower oil rations, only linoleic acid content was increased, even though soybean oil contained seven to eight per cent of linolenic acid. Feeding safflower oil resulted in the largest increase in linoleic acid content of egg fat, although feeding both linseed and soybean oil doubled the egg fat linoleic acid level. Tallow had no effect on the concentration of these two essential fatty acids in the egg yolk.

Horlick and O'Neil (1958) fed hens, for eight weeks, a ration containing 10% sun safflower seed oil which, in turn, contained 60% linoleic acid, and obtained nearly a sixfold increase in the linoleic acid content (5.65 to 30.40) of egg fat. The increase in linoleic acid was largely at the expense of the oleic acid which declined by about half (from 49.9 to 28%). Chen et al. (1965) confirmed these observations with later experiments.

Wheeler et al. (1959) compared the total lipids of egg yolk from hens fed diets containing 5, 10, 15, 22.2 or 30% safflower seed oil; 22.2 or 30% linseed oil; and 10% cottonseed, corn or soybean oil with those produced by hens fed a stock ration. They observed that the linoleic acid content of eggs from hens fed safflower oil or cottonseed oil (no linoleic acid) was approximately proportional to the level of linoleic acid in the diet. In the case of hens fed diets containing linolenic acid as supplied by corn, soybean or linseed oil, linoleic acid was not deposited in eggs as efficiently as in eggs of hens fed safflower oil or cottonseed oil. This was ascribed to an antagonistic effect of linolenic acid on incorporation of linoleic acid into yolk fat. In all the diets tested, except the linseed oil diet, an increase in linoleic acid was accompanied by a corresponding decrease in oleic and palmitoleic acid. Only when an extremely high level of linoleic acid (40%) was obtained in the yolk was a slight decrease in palmitic acid observed. With the linseed oil diet, the increase in polyunsaturated fatty acids was associated with a decrease in both oleic, palmitoleic and palmitic acids. Stearic acid remained unchanged in all the different diets. In rats, it has been shown that the conversion of linoleic acid to arachidonic

acid in adipose tissue is partially inhibited by dietary linoleic acid in adipose tissue (Mohrhauer and Holman, 1963a).

Skellon et al. (1962) investigated the lipid composition of egg yolk from hens fed a sunflower seed oil (12 to 16%), or maize oil diets. This was compared with that of yolk lipids from a control (low-fat) group. The data exhibited a significant fall in oleic acid (44 to 34%) and an increase in linoleic (10 to 24%) and stearic acid in yolk lipids from non-control rations.

Evans et al. (1960) supplemented cottonseed oil (2.5%) or various fractions (0.3 to 2.1%) of cottonseed oil to laying hens, and found that there was no great influence on the composition of egg yolk lipids, except that they contained a higher concentration of stearic acid than did dietary lipids. Therefore, they felt that supplementing the diet with fats did not greatly alter the composition of fatty acids in the egg yolk lipids, unless extremely high levels of fat were used. Later on, the same workers (Evans et al. 1961) found that eggs from hens fed the ration supplemented with either 2.5% crude cottonseed or 0.67% Sterculia foetida seed oil, had increasing proportions of stearic and linoleic acids, and a decreasing level of oleic acid. The increase in stearic

acid level due to the above treatments was postulated as being due to a stimulation of selective transfer of stearic acid to egg yolk and/or increased formation of stearic acid from fat or non-fat sources.

In a subsequent study, Evans et al. (1963) concluded that the active agent in cottonseed or Sterculia foetida oil upset the normal synthesis of fatty acids in hens, and caused formation of high concentration of stearic acid in the yolk, regardless of whether the source of fatty acid was from carbohydrates or other fats such as corn oil or olive oil. As a whole, their data indicate that the composition of egg yolk lipid was not always a simple reflection of the dietary fatty acid components, although in most instances, it was slightly modified by dietary fat.

In rats, the modification of fatty acid composition of milk fat by the fat ingested by the mother has been well documented (Beare et al. 1961). They showed that when rats were fed a low-fat ration, they secreted predominantly saturated fatty acid (C_{16}) in milk, whereas a preponderant concentration of $C_{18:2}$ and $C_{18:1}$ appeared in the milk when corn oil or mixture of lard and olive oil was fed, respectively. Rats fed rapeseed oil secreted milk fat containing eicosenoic and erucic acids but

at lesser concentration than in the original oil. In another report, Beare (1961) noted that rats, which had been given erucic acid for several generations secreted milk containing somewhat less than half the amount of the erucic acid produced by the initial generation. Thus, it appears that over long periods of time there was some adaptation in utilization of erucic acid.

Lossow and Chaikoff (1958) injected tripalmitin-1-C^{14} and octoanoate-1-C^{14} intravenously and observed these labelled fatty acids in milk. In their study, shorter chain saturated fatty acids, which were absent in the diet, were present in considerable amount in milk fat. They suggested that except in the case of low-fat diets, the milk fatty acid pattern reflected that of dietary fat.

Effect of Dietary Fat on Adipose Tissue

The effect of dietary fat on the composition of depot fat in the chicken has been studied by several investigators. In most instances, it has been demonstrated that dietary fat exerts a marked effect on the composition of depot fat (Chomyszym, 1955; Coppock et al. 1962). Cruickshank (1934) observed the iodine value of various tissues (skin, muscle, adipose tissue) of hens, and found that these tissues appeared to be uniform in fatty acid

composition. Individuals, however, varied slightly in rate and degree of response to change in diet.

The physiological condition of the bird (laying, non-laying or brooding) as well as the capacity for food consumption, seems to influence the depot fat. Normally, depot fat appears to be markedly influenced by the fatty acids ingested, irrespective of their degree of saturation. It was also shown that saturation took place more slowly than unsaturation, both during the production of a more saturated fat than normal, and during the production of normal fat from an abnormally unsaturated one. Since various factors, such as palatability or ratio of fat to carbohydrates in the diet, may produce this effect, it need not necessarily mean that the hens selected the unsaturated fatty acids more readily than saturated fatty acids.

Sell and Hodgson (1962) observed that adipose tissue of chicks receiving animal tallow reflected the relatively high stearic-oleic acids and low linoleic acid content of the diet. When the diet was supplemented with eight per cent soybean or sunflower seed oil, they found a distinct decrease in the palmitic- palmitoleic acid level of the adipose tissue with a simultaneous increase in linoleic acid. Chicks receiving dietary rapeseed oil

sembled that of body fat (Ingull et al. 1959). Evans et al. (1962) failed to obtain a significant change in fatty acid composition of adipose tissue in his experiment, and the fatty acid distribution in depot fat was intermediate between that in plasma and in the diet. They stated that most of the dietary fat may have been deposited in adipose stores before it was altered in the liver.

Machlin and Gordon (1962) observed that hens fed purified diets containing either 15% hydrogenated coconut oil or safflower oil, followed a change in the fatty acid composition of liver and heart, which was similar to that observed in the young growing chicks. These changes were dependent upon and reflected the composition of the fat consumed. However, in chicks, ingestion of $C_{18:2}$ increased $C_{20:4}$ content in these tissues (Machlin and Gordon, 1961), whereas in hens $C_{20:4}$ was not affected by high or low level of dietary $C_{18:2}$ acid. This would mean that $C_{20:4}$ in the lipid has a slower turnover rate than shorter chain acids ($C_{18:2}$) in hens' tissues as compared to that of chicks, or that hens have large reserves of $C_{18:2}$ in adipose tissue, which is enough to provide for the conversion of $C_{20:4}$ when necessary.

Couch et al. (1964) conducted an investigation with hens fed a basal ration supplemented with 10% corn

oil, lard or hydrogenated coconut oil, each at the expense of cerelose in the basal diet. Their results indicated that abdominal adipose tissue tended to rapidly approach the degree of saturation of the dietary fat. These researchers reported that absorbed excess fat was deposited in the abdominal adipose tissue with a minimum of change, whereas in other tissue, an attempt was made by the hen to maintain a lipid which was more characteristic of the species so far as fatty acid composition was concerned.

Carroll (1965), after a perusal of the literature, stated that in lower forms of animal life (fish) the deposition of dietary fat in tissue fat was relatively straight- forward and endogenous synthesis played only a minor role in determining the fatty acid composition of the depot fat. In highly evoluted animals, endogenous synthesis from non-fat precursors becomes more important and was largely responsible for the fatty acid composition of depot fat. Long-chain saturated fatty acids (C_{16} and C_{18}) are normally formed from short-chain precursors. The major monounsaturated acids ($C_{16:1}$ and $C_{18:1}$) appear to be formed largely from C_{16} and C_{18} respectively. Moreover, it has been shown that the decrease in degree of saturation of fatty acids result from the insertion of additional double bonds between the carboxyl group and the existing

double bonds. Dietary fat also seems to play a part in the regulation of biosynthesis of fat in the body, but it does not seem to have a specific effect (Hill et al. 1958).

Genetic Influence on the Fatty Acid Composition of Egg Yolk and Adipose Tissue

Little information is available about the genetic differences among strains and breeds of chickens in so far as fatty acid composition of egg or body fat is concerned. Edwards et al. (1960) in the hope of seeking information about genetic influences, made a survey of chemical constituents of egg from eight strains of chickens. They found that the total fat content of eggs varied among strains from about 44% for the Cornell Random breed, to 47% for the White Plymouth Rock. There were distinct differences in iodine value among strains. Arroyave et al. (1957) did not find any significant differences among breeds of hen with respect to fat content of egg yolk, but observed that per cent of yolk fat increased with increase in age of hens.

In a study of five strains of chickens (representing three breeds) for fatty acid composition of yolk lipids, Edwards (1964) found that the relative amount of certain fatty acids ($C_{16:1}$, $C_{18:0}$, $C_{18:2}$ and $C_{20:4}$) varied

among strains. However, the differences among strains were usually much less than those observed among individuals within a strain.

Chen et al. (1965) used two strains of hens; a laying type (S. C. white Leghorn) and a meat type (Arkansas Silver) to study possible influence of different breeds on the fatty acid composition of egg lipid in response to a control diet as well as different dietary fats. They found that the differences in fatty acid composition of yolk lipid exhibited by the two different bird types were not always the same in each individual fraction of the yolk lipid. Supplementation of the ration with linseed oil or coconut oil, had no influence on the total fatty acid of the eggs from the two strains, but phospholipids and glycerides did display some differences related to ration treatments. The small differences between strains observed led these workers to conclude that variation due to the breed was of relatively minor importance with respect to fatty acid composition of the egg fat.

EXPERIMENTAL PROCEDURE

Three strains of chickens, Pearlettes (Pe), Shaver (Sh) and Clarks (Cl), which are commercial egg production hybrids, were selected for this study. The Pe and Sh were of the light egg type origin and the Cl was of heavy meat type origin. One hundred chicks from each strain were hatched and reared in thermostatically-controlled, electrically-heated batteries, equipped with wire floors. A complete chick starter was fed to all of the chicks until eight weeks of age. This diet was replaced by a growing diet and fed to about 19 weeks of age. Mash and water were provided *ad libitum*. The chicks were vaccinated at one week and twelve weeks of age against bronchitis. At five months of age, 30 well-grown pullets of each strain were selected, and allotted randomly into three groups; each consisted of 10 pullets from each of the three strains. The pullets were placed into individual cages, and fed a standard laying diet containing 3.7% fat. Individual egg production records were kept after all the birds attained 50% hen-day egg production. At this time, 10 birds of each strain were fed each of the three experimental rations. Feed consumption data were recorded monthly. The three

TABLE 1a

COMPOSITION OF THE EXPERIMENTAL RATIONS

Ingredients	Low-Fat Ration	Soybean Oil Ration	Rapeseed Oil Ration
Ground wheat (14% of protein)	36.0%	36.0%	36.0%
Soybean meal (45% of protein)	24.0	24.0	24.0
Dehydrated alfalfa meal (17% of protein)	2.0	2.0	2.0
Meat and bone scrap (50% of protein)	2.0	2.0	2.0
Ground limestone	4.5	4.5	4.5
Def. rock phosphate	2.0	2.0	2.0
Vitamin premix[1]	1.0	1.0	1.0
Salt premix[2]	0.5	0.5	0.5
Animal tallow	2.0	-	-
Soybean oil	-	14.0	-
Rapeseed oil	-	-	14.0
Corn starch	26.0	-	-
Total	100.0	86.0	86.0
Calculated Analysis			
Protein (%)	17.2	20.0	20.0
Fat (%)	3.0	17.4	17.4
Crude fiber (%)	3.0	3.5	3.5
Calcium (%)	2.7	3.1	3.1
Phosphorus (%)	0.7	0.8	0.8
Metabolizable energy (kcal./kg.)	2800	3440	3440

[1]Vitamin premix supplied the following per kilogram of ration: Vitamin A, 7050 I.U.; Vitamin D_3, 818 I.C.U.; Vitamin E, 11 mg.; Vitamin B_{12}, 11 mg.; Choline, 136.4 mg.; Riboflavin, 2.75 mg.; Naicin, 8.25 mg.; Pantotenic acid, 5.5 mg.; Methionine, 0.05%; Santoquin, 0.0125%.

[2]Salt and trace mineral premix supplied the following per kilogram of ration: Manganese, 242 mg.; Zinc, 121 mg.; Sodium chloride, 10.16 mg.

TABLE 1b

FATTY ACID COMPOSITION (AS % OF TOTAL METHYL ESTERS)

OF THE DIETARY FATS (ETHER EXTRACT)

	Low Fat		Soybean Oil		Rapeseed Oil	
Fatty Acid	Ration	g./100 g. Feed	Ration	g./100 g. Feed	Ration	g./100 g. Feed
C_{14}	2.97	0.06	0.49	0.07	0.56	.08
C_{16}	27.39	.55	14.13	1.98	8.87	1.24
$C_{16:1}$	2.92	.06	0.63	0.09	1.86	.26
C_{18}	8.76	.18	3.22	0.45	2.61	.37
$C_{18:1}$	30.67	.61	22.89	3.20	28.46	3.98
$C_{18:2}$	22.64	.45	50.60	7.08	18.63	2.61
$C_{18:3}$	4.66	.09	8.05	1.13	17.23	2.41
C_{20}	0	0	0	0	0	0
$C_{22:1}$	0	0	0	0	21.79	3.05

experimental rations varied in source and level of fat supplementation. Ingredient composition of rations is shown in Table 1a. The major energy source of the low-fat ration was supplied by corn starch, while the other two were supplemented with either 14% soybean oil or rapeseed oil. The oils were substituted for corn starch on a caloric basis and, thus the nutrient to caloric ratio was similar for all three rations. Due to the high fat content of the rations, fresh rations were prepared biweekly and stored at low temperature (50°F).

For lipid analysis, eggs were collected during three periods of the experiment. The collection periods began at 14, 90 and 180 days when three consecutive eggs were saved for analysis. After each collection, approximately 10 g. of abdominal fat were removed from each hen by biopsy for fatty acid analysis. At termination of the experiment, six birds from each ration treatment (two of each strain), were killed bloodlessly. Various stages of developing yolks were taken from the ovaries. They were divided into three catagories. The sizes were: one-quarter inch in diameter or less; from one-quarter to half an inch, and from half of an inch to three-quarter inch in diameter. Yolks within each category were pooled and stored at -20°C.

The whole egg was weighed, after which it was

broken and the albumen height was measured with a micrometer. Subsequently, haugh unit (a measurement of egg quality) was calculated by the "Interior Quality Calculator of Egg". The yolks were separated on an "egg yolk separator", the albumen was collected in a petri dish, the thick albumen was separated from the thin. Egg yolk, thin and thick albumen and shell weights were recorded. The three yolks from one hen were mixed thoroughly and stored at -20°C.

Methyl esters of fatty acids of lipids in the egg yolk and adipose tissue were prepared by a modification of the procedure of Metcalfe et al. (1961). Approximately two grams of egg yolk sample were dried by lyophilization, and 0.15 g. of dried sample was placed directly into three milliliters of boron trifloride-methanol reagent in a screw-cap tube. With the cap loosely fitted, the tube was placed into a hot water bath at 65 to 70°C. After 10 minutes, the tube was withdrawn, and the screw-cap tightened. The sample was then incubated in an oven at 65 to 70°C for 12 hours. This was followed by cooling the mixture to room temperature, and adding 10 ml. of pentane plus five millileters distilled water. The tubes were then shaken vigorously and allowed to stand until a clear supernatant layer was obtained. The pentane layer which contained the methyl esters, was transfered carefully to another vial, where the solvent was

evaporated with the aid of mild heat; the methyl esters were stored in a refrigerator until analysis. The same procedure was applied to the esterification of adipose tissue, except that the sample was not freeze-dried but fresh tissue was used.

Fatty acid composition of the lipids was determined using the F & M Model 700 Gas Chromatograph, equipped with a hot-wire thermoconductivity detector. A five-foot, stainless steel column of one-eighth of an inch in outside diameter was used. Chromosorb W (mesh size 80/100), coated with 10% diethylene glycol succinate polyester by weight (stationary phase), was used as the column packing material. Operating temperatures were as follows: column, 175°C; detector, 260°C; and injection port, 275°C. A filament current of 250 milliamperes was used. The rate of helium flow (mobile phase) through the column was 35 ml per minute. A Sargent recorder, equipped with a disc integrator, Model SR, was used to record the chromatograms. Identification of fatty acids was accomplished by comparison of the retention time of different chromatogram peaks with those of known fatty acids. The per cent composition of fatty acids was calculated on the basis of the ratio of peak areas as determined by the integrator.

The data were subjected to analysis of variance

as described by Snedecor (1956). All the analyses of variance appear in tables in the Appendix.

RESULTS

Influence of Dietary Fats and Strains on Feed Consumption and Feed Efficiency

Increasing dietary fat was generally associated with decreased feed consumption (Table 2a and Table 2b). With low-fat ration, where carbohydrate was used to supply a large portion of the energy, the highest consumption of feed was observed. Feed consumption of the hens decreased when a portion of the carbohydrate was replaced by soybean oil on a caloric basis, and the relative decrease in feed consumption was in proportion to the increase in ration energy level (Table 2b). When soybean oil was replaced by rapeseed oil (containing a large proportion of erucic acid), feed consumption was significantly ($P< 0.01$) decreased (Table 2c). A significant ($P< 0.01$) difference among strains in terms of feed consumption was also observed (Table 2b). Among the strains investigated, strain Sh consumed the least amount of feed while strain Cl consumed the most with strain Pe ranking intermediate (Table 2b). There was a significant ($P< 0.01$) period effect on feed intake. The interaction of ration x period was highly significant ($P< 0.01$), and was attributed to the inconsistent changes in feed consumption with respect to

TABLE 2a

FEED CONSUMPTION (GRAMS OF FEED/HEN DAY) BY THREE STRAINS OF HENS FED DIFFERENT RATIONS

	Low Fat			Soybean Oil			Rapeseed Oil		
Strain	Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
Period I	111.94	106.72	123.12	107.41	100.01	114.27	100.93	93.47	102.55
II	121.95	115.41	123.06	101.23	98.25	97.04	91.35	93.37	100.42
III	124.38	120.60	126.36	104.58	102.97	93.98	79.74	78.00	83.97
Mean	119.42	114.24	124.18	104.41	100.41	101.80	90.67	88.28	95.65

TABLE 2b

SUMMARY OF FEED CONSUMPTION (GRAMS OF FEED/HEN DAY) BY THREE STRAINS OF HENS FED DIFFERENT RATIONS FOR ALL PERIODS

Ration	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Strain Pe	119.42	104.41	90.67	104.83
Sh	114.24	100.41	88.28	100.98
Cl	124.18	101.41	95.65	107.21
Mean	119.28	102.21	91.53	

TABLE 3a

EFFICIENCY OF FEED UTILIZATION (GRAMS OF FEED/GRAM OF EGG)

OF THREE STRAINS OF HENS FED DIFFERENT RATIONS

Ration	Low Fat			Soybean Oil			Rapeseed Oil		
Strain	Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
Period I	2.54	2.36	2.93	2.49	2.21	2.77	4.10	2.66	3.68
II	2.72	2.70	3.35	2.52	2.21	2.91	3.65	2.75	4.07
III	2.93	2.80	4.19	2.52	2.28	3.12	5.16	2.90	4.80
Mean	2.73	2.62	3.49	2.51	2.23	2.93	4.30	2.77	4.18

TABLE 3b

SUMMARY OF EFFICIENCY OF FEED UTILIZATION (GRAMS OF FEED/GRAM OF EGG) OF THREE STRAINS OF HENS FED DIFFERENT RATION FOR ALL PERIODS

Ration	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Strain				
Pe	2.73	2.51	4.30	3.18
Sh	2.62	2.23	2.77	2.54
Cl	3.49	2.93	4.18	3.53
Mean	2.95	2.56	3.75	

various rations. For instance, when the low-fat diet was fed, there was an increase in feed consumption with time. In contrast, hens receiving high-fat rations consumed less feed.

Hens receiving the soybean oil diet exhibited a more efficient utilization of feed than those fed the low-fat rations (Tables 3a and 3b). However, when rapeseed oil was substituted for soybean oil on a caloric basis, feed required per gram of egg produced increased from 2.56 to 3.75 g., a value even higher than found in the case of the low-fat diet (2.95). Amongst different strains studied, the Sh strain utilized feed most efficiently. However, there was a significant ($P < 0.01$) strain x ration interaction (Table 3c) illustrating that effects of the same ration treatment upon different strains were not always consistent. For example, strain Pe utilized the low-fat and the soybean oil rations better than Cl strain, whereas Cl strain utilized the rapeseed oil diet better than did strain Pe. Efficiency of feed utilization differed significantly ($P < 0.01$) from period to period, with efficiency of feed utilization decreasing with time on experiment.

Per Cent of Hen Day Production and the Total Weight of Egg Produced Per Hen Day

Hens fed the low-fat diet were able to maintain

TABLE 4a

RATE OF HEN-DAY EGG PRODUCTION BY THREE STRAINS OF HENS FED DIFFERENT RATIONS

Ration	Low Fat			Soybean Oil			Rapeseed Oil		
Strain	Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
Period	%	%	%	%	%	%	%	%	%
I	83.21	81.43	75.71	77.86	78.97	73.21	55.71	74.29	57.50
II	81.49	74.03	63.76	68.91	77.29	57.38	53.33	67.86	48.39
III	72.40	69.84	49.80	65.87	72.10	48.70	30.59	51.25	32.54
Mean	79.03	75.10	63.09	70.88	76.12	59.76	46.54	64.47	46.14

TABLE 4b

SUMMARY OF RATE OF HEN-DAY EGG PRODUCTION BY THREE STRAINS OF HENS FED DIFFERENT RATIONS FOR ALL PERIODS

Ration	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Strain	%	%	%	%
Pe	79.03	70.88	46.54	65.48
Sh	75.10	76.12	64.47	71.90
Cl	63.09	59.76	46.14	56.33
Mean	72.41	68.92	52.38	

72.4% hen day production (Tables 4a and 4b). Inclusion of soybean oil in the ration decreased rate of egg production to 68.9%, while the use of rapeseed oil caused a further reduction in egg production. Amongst the strains investigated, Sh strain produced eggs at the highest rate. The Pe strain produced at an intermediate rate while strain Cl produced eggs at a comparatively low rate (Table 4b). The strain x ration interaction was significant ($P < 0.01$), (Table 4c) indicating that the response of each strain to different ration treatments was not due to ration treatments alone. For instance, strain Pe produced more eggs when fed the low-fat diet than when fed the ration containing soybean oil, whereas the trend was the reverse in the case of strain Sh. When the rapeseed oil diet was fed, the production of strain Pe equalled that of Cl strain (Table 4a). A marked period effect was also noticed (Table 4c). This was a reflection of a significant ($P < 0.01$) reduction in egg production with increasing age. In addition, significant ($P < 0.05$) strain x period and ration x period interactions were observed. These interactions show that there was a real difference among strains or rations as to how rapidly the initial rate of egg production decreased with age.

Apparently, hens maintained on rations with con-

TABLE 5a

TOTAL WEIGHT OF EGGS (GRAMS OF EGG/HEN-DAY) PRODUCED BY THE THREE STRAINS OF HENS FED DIFFERENT RATIONS

Ration	Low Fat			Soybean Oil			Rapeseed Oil		
Strain	Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
Period I	44.05	45.12	41.96	43.21	45.24	41.29	24.64	35.09	27.85
II	44.77	42.76	36.76	40.01	44.45	33.39	25.03	33.97	24.69
III	42.18	43.02	30.15	40.96	45.14	30.17	15.46	26.90	17.51
Mean	43.67	43.63	36.29	41.39	44.94	34.95	21.71	31.99	23.35

TABLE 5b

SUMMARY OF THE TOTAL WEIGHT OF EGGS (GRAMS OF EGG/HEN-DAY) PRODUCED BY THREE STRAINS OF HENS FED DIFFERENT RATIONS FOR ALL PERIODS

Ration	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Strain				
Pe	43.67	41.39	21.71	35.59
Sh	43.63	44.94	31.99	40.19
Cl	36.29	34.95	23.35	31.53
Mean	41.19	40.43	25.68	

stant energy-to-nutrient ratios (soybean oil or low-fat diet) were able to produce a similar amount of egg per hen day regardless of source and level of energy. Less grams of egg were produced by hens receiving the rapeseed oil diet (Table 5a and 5b). This implies that somehow a disturbance in normal egg formation was involved. A significant ($P < 0.01$) strain difference with respect to the amount of egg produced was noted (Table 5c). In general, grams of egg produced by Sh strain was highest (40.19 g.), followed by Pe strain (35.59 g.) and then Cl strain (31.53 g.). Significant ($P < 0.05$) strain x ration interaction revealed an inconsistent effect of rations upon different strains. Strains Pe and Sh fed the low-fat diet maintained higher production than strain Cl. Increasing dietary fat to 14% of the total ration improved the amount of egg produced by strain Sh, while a slight reduction was observed in Pe strain. On the rapeseed oil diet, Pe strain had the poorest production of the three strains (Table 5b). Significant ($P < 0.01$) period effects indicated that hens laid less grams of egg per hen day as they became older.

Influence of Rations and Strains on the Weight of Individual Egg and Yolk

Individual eggs from hens receiving the soybean

TABLE 6a

AVERAGE EGG WEIGHT (GRAMS) FROM THREE STRAINS OF HENS FED DIFFERENT RATIONS

Ration	Low Fat			Soybean Oil			Rapeseed Oil		
Strain	Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
Period I	53.02	55.60	55.30	55.24	57.09	56.53	44.77	46.94	48.22
II	57.27	59.93	59.14	60.47	61.73	59.83	50.14	52.20	52.58
III	59.98	62.40	61.24	63.67	63.94	62.59	52.01	52.18	55.65
Mean	56.76	59.31	58.56	59.80	60.92	59.65	48.97	50.44	52.15

TABLE 6b

SUMMARY OF AVERAGE EGG WEIGHT (GRAMS) FOR THREE STRAINS OF HENS FED DIFFERENT RATIONS FOR ALL PERIODS

Ration	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Strain Pe	56.76	59.80	48.97	55.18
Sh	59.31	60.92	50.44	56.89
Cl	58.56	59.65	52.15	56.79
Mean	58.21	60.12	50.52	

TABLE 7a

AVERAGE OF YOLK WEIGHT (GRAMS) FROM THREE STRAINS

OF HENS FED DIFFERENT RATIONS

Ration	Low Fat			Soybean Oil			Rapeseed Oil		
Strain	Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
Period I	15.78	16.08	16.43	15.68	16.21	16.15	12.18	11.88	13.15
II	18.16	17.98	18.69	18.24	18.39	18.83	13.94	13.39	14.85
III	19.41	18.88	20.53	19.93	19.71	20.00	15.96	14.16	16.23
Mean	17.78	17.65	18.55	17.95	18.10	18.33	14.02	13.14	14.74

TABLE 7b

SUMMARY OF YOLK WEIGHT (GRAMS) FROM THREE STRAINS OF HENS FED DIFFERENT RATIONS FOR ALL PERIODS

Ration	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Strain				
Pe	17.78	17.95	14.02	16.58
Sh	17.65	18.13	13.14	16.30
Cl	18.55	18.33	14.74	17.21
Mean	17.99	18.13	13.96	

oil ration were heavier than those from hens fed the low-fat ration, and both were much heavier than eggs produced by hens fed rapeseed oil diet (Table 6b). A similar trend was observed in yolk weight (Table 7b). Variations in individual egg weight due to strain differences in response to various rations were observed although the strain x ration interaction was not significant (Table 6c). In general, average egg weight was considerably heavier for Sh and Cl strains than Pe. Yolk weight in strain Cl was higher than in the other two strains. Significant ($P < 0.01$) period effects on the egg and yolk weight indicated that size of egg and yolk increased in all strains with increasing age regardless of ration treatments (Table 7c).

Influence of Dietary Fats on the Fatty Acid Composition of Egg Yolk Lipids

All three strains gave a different picture for fatty acid composition of egg yolk on different ration treatments (Tables 8 and 9). Analysis of variance of individual fatty acids within periods and the sum of all periods indicated a distinct influence of both treatments and strains on lipid composition.

The fact that only hens receiving the rapeseed oil diet contained erucic acid in egg yolk fat, indicated that dietary lipids greatly influenced the composition of

TABLE 8 (Continued)

Fatty Acid	Period	Basal Ration			Soybean Oil Ration			Rapeseed Oil Ration		
		Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
$C_{18:3}$	I	0.7±0.7	0.7±0.4	0.6±0.2	1.8±0.4	1.8±0.3	2.2±0.5	2.7±1.0	3.5±0.9	3.2±0.8
	II	0.3±0.1	0.6±0.2	0.3±0.1	2.9±2.1	1.8±0.5	1.7±0.7	1.9±0.4	2.7±0.9	2.1±1.4
	III	0.5±0.2	1.0±0.7	1.0±0.5	2.0±0.5	1.7±0.6	2.2±0.3	1.8±0.6	2.2±0.7	2.2±0.7
C_{20}	I	0.3±0.1	0.7±0.1	0.6±0.1	0	0	0	0.3±0.2	0.2±0.2	0.1±0.2
	II	0.1±0.1	0.2±0.2	0.1±0.1	0	0	0	0	0	0
	III	0.4±0.2	0.3±0.3	0.3±0.4	0	0	0	0	0	0
$C_{22:1}$	I	0	0	0	0	0	0	1.5±0.6	1.1±0.3	1.4±0.4
	II	0	0	0	0	0	0	0.9±0.2	1.1±0.3	1.6±0.5
	III	0	0	0	0	0	0	1.5±0.5	1.2±0.3	1.2±0.3
Cy	II	0.7±0.4	0.9±0.6	1.0±0.2	1.1±0.3	1.3±0.5	1.0±0.5	0	0	0

[a]Mean of ten replicates.
[b]Standard deviation.

TABLE 9

FATTY ACID COMPOSITION (AS % OF TOTAL METHYL ESTERS) OF TOTAL LIPID IN ADIPOSE TISSUE

Fatty Acid	Period	Low-Fat Ration			Soybean Oil Ration			Rapeseed Oil Ration		
		Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
C_{14}	I	1.1[a]±0.2[b]	1.2±0.3	1.1±0.2	0.7±0.2	0.6±0.1	0.6±0.1	0.7±0.1	0.9±0.42	0.7±0.1
	II	1.4 ±0.2	1.2±0.2	1.3±0.2	0.6±0.2	0.3±0.1	0.5±0.1	0.6±0.2	0.2±0.1	0.5±0.1
C_{16}	I	25.2 ±1.6	23.9±1.6	25.7±1.3	17.1±4.0	16.8±0.8	19.6±1.7	19.5±2.0	17.5±1.8	19.6±1.9
	II	22.9 ±2.0	22.2±2.1	24.4±2.5	12.9±1.8	11.6±1.0	14.3±1.8	11.5±2.5	8.9±1.4	12.0±2.1
$C_{16:1}$	I	6.9 ±1.0	7.3±1.4	7.4±1.4	3.7±1.8	3.6±1.1	3.6±0.9	4.7±1.4	4.1±1.5	4.0±0.8
	II	7.6 ±1.9	6.9±1.6	6.9±1.4	2.3±0.8	1.5±0.4	1.6±0.5	2.9±1.0	1.3±0.5	2.5±1.0
C_{18}	I	4.2 ±0.8	4.5±1.0	3.9±0.6	3.3±0.6	3.7±0.7	3.4±0.8	4.5±2.8	3.9±0.5	3.0±0.7
	II	3.7 ±1.0	4.0±1.0	4.1±0.9	2.7±0.7	2.9±0.7	2.9±1.6	2.0±0.7	1.7±0.4	2.3±0.9
$C_{18:1}$	I	49.5 ±2.5	49.0±2.4	48.4±3.0	37.9±2.2	37.1±3.0	36.9±2.2	47.8±1.9	46.1±2.3	46.0±2.2
	II	52.1 ±2.5	53.6±3.6	52.2±4.7	32.9±1.9	29.3±1.3	33.6±1.9	47.6±2.9	40.9±4.5	44.3±4.0
$C_{18:2}$	I	12.3 ±1.3	13.2±1.1	12.8±2.5	34.6±5.5	35.1±3.3	32.8±2.4	15.0±2.3	17.1±2.8	18.4±2.1
	II	11.5 ±1.0	11.0±1.7	10.3±1.1	45.1±4.1	49.9±2.2	43.6±2.7	18.8±1.6	17.7±1.2	20.0±4.0
$C_{18:3}$	I	1.4 ±0.6	0.9±0.5	0.7±0.2	2.8±0.7	3.2±0.7	3.1±1.0	5.2±1.8	6.9±1.7	6.3±3.1
	II	0.9 ±0.2	1.0±0.4	0.9±0.3	3.5±1.4	4.5±0.2	3.5±0.7	11.3±2.3	21.3±3.0	15.3±2.5
$C_{22:1}$	I	0	0	0	0	0	0	2.7±0.7	3.5±1.7	1.8±1.3
	II	0	0	0	0	0	0	5.3±3.3	7.9±3.1	3.0±1.3

[a]Mean of ten replicates.
[b]Standard deviation.

the yolk fat. The changes in fatty acid composition were roughly proportional to the respective dietary pattern (Figure 1 and Table 8). Eggs from hens receiving the low-fat diet (high carbohydrate) contained a higher proportion of C_{14}, $C_{16:1}$ and C_{18} than those from hens fed high-fat diets (Tables 10a, 12a and 13a). Oleic acid ($C_{18:1}$) represented more than half (52%) of the total fatty acids in the yolk (Table 14a) followed by C_{16} (28%) (Table 11a). A markedly lower level of $C_{18:2}$ and $C_{18:3}$ was observed in egg yolks from hens fed the low fat as compared with eggs produced by hen fed rations containing soybean or rapeseed oil (Tables 15a and 16a).

Addition of soybean oil led to an alteration in the distribution of almost all the fatty acids in the yolk. Linoleic acid ($C_{18:2}$), being the dominant fatty acid in the diet, was deposited at a very high level (Table 15a). This change was accompanied by a relative decrease in $C_{16:1}$ and $C_{18:1}$ (Table 8). Although about 8% of $C_{18:3}$ was included in the soybean oil diet, very little of this acid (1.99%) was found in egg yolk lipids.

Inclusion of rapeseed oil in the ration resulted in little change in the concentration of $C_{18:1}$ in yolk in comparison with the low-fat ration. Although the C_{16} content of the rapeseed oil diet was about six per cent less

TABLE 10a

SUMMARY OF C_{14} CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	0.49	0.28	0.29	0.35
	A	1.24	0.60	0.67	0.84
Sh	Y	0.48	0.32	0.29	0.36
	A	1.21	0.46	0.58	0.75
Cl	Y	0.45	0.27	0.24	0.32
	A	1.22	0.56	0.60	0.80
Mean	Y	0.47	0.29	0.27	
	A	1.22	0.54	0.62	

TABLE 11a

SUMMARY OF C_{16} CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	28.07	24.13	22.55	24.91
	A	24.05	15.01	15.52	18.20
Sh	Y	27.48	23.31	22.47	24.42
	A	23.09	14.21	13.16	16.82
Cl	Y	27.61	22.33	21.05	23.66
	A	25.02	16.95	15.79	19.25
Mean	Y	27.72	23.25	22.02	
	A	24.05	15.33	14.82	

TABLE 12a

SUMMARY OF $C_{16:1}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	4.41	1.81	2.90	3.04
	A	6.99	3.02	3.80	4.60
Sh	Y	3.92	2.33	2.90	3.05
	A	7.10	2.53	2.69	4.11
Cl	Y	4.10	2.14	2.89	3.04
	A	7.13	2.57	3.26	4.32
Mean	Y	4.15	2.09	2.90	
	A	7.07	2.70	3.25	

TABLE 13a

SUMMARY OF C_{18} CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	7.07	7.75	6.03	7.13
	A	3.91	2.99	3.22	3.37
Sh	Y	7.81	8.52	5.87	7.40
	A	4.23	3.31	2.82	3.45
Cl	Y	6.87	7.97	5.43	6.76
	A	3.97	3.18	2.65	3.26
Mean	Y	7.25	8.08	5.78	
	A	4.04	3.16	2.89	

TABLE 14a

SUMMARY OF $C_{18:1}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	52.39	35.20	52.89	46.83
	A	50.80	35.37	47.68	44.62
Sh	Y	51.80	34.12	51.28	45.73
	A	51.31	33.19	43.50	42.66
Cl	Y	53.86	35.38	52.68	47.31
	A	50.30	35.27	45.14	43.57
Mean	Y	52.68	34.90	52.28	
	A	50.80	34.61	45.44	

TABLE 15a

SUMMARY OF $C_{18:2}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	6.57	28.23	11.82	15.54
	A	11.86	39.87	16.89	22.87
Sh	Y	7.03	29.19	13.21	16.48
	A	12.11	42.48	17.43	24.00
Cl	Y	5.82	29.59	13.61	16.34
	A	11.55	38.17	19.23	22.99
Mean	Y	6.47	29.00	12.88	
	A	11.84	40.17	17.85	

TABLE 16a

SUMMARY OF $C_{18:3}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	0.49	2.23	2.12	1.61
	A	1.15	3.15	8.23	4.18
Sh	Y	0.79	1.77	2.81	1.79
	A	0.97	3.84	14.12	6.31
Cl	Y	0.63	1.99	2.66	1.76
	A	0.83	3.31	10.96	5.03
Mean	Y	0.64	2.00	2.53	
	A	0.98	3.43	11.10	

than the soybean oil ration, there was very little difference between these two treatments in C_{16} content of egg yolk (Table 11a). Change of $C_{18:2}$ was proportional to that of the dietary level. It was interesting to note that only 2.53% of $C_{18:3}$ appeared in the yolk, irrespective of the fact that the rapeseed oil ration contained 17% of this fatty acid (Table 2a and 16a). On the other hand, yolks from hens fed the soybean oil ration (8% $C_{18:3}$) contained approximately the same amount of this fatty acid (1.99%) as hens fed rapeseed oil. This low deposition of $C_{18:3}$ in egg yolk was not accompanied by an increase in $C_{18:2}$ content of the same yolk, nor were highly unsaturated long chain fatty acids ($C_{20:4}$) increased. A decrease in $C_{18:3}$ and $C_{18:2}$ with a simultaneous increase of $C_{18:1}$ and $C_{16:1}$ was also observed in the yolks. In the case of $C_{22:1}$ (Table 17a), only a small proportion (1.5%) was incorporated into egg fat, even though this fatty acid comprised 21% of the dietary fat. The saturated fatty acids such as palmitic (C_{16}) and stearic (C_{18}) in yolks from hens fed high-fat rations were present in higher concentration than that found in the diet or adipose tissue (Figure 1).

Period effects on the response of egg yolk fatty acids to changes of dietary fats were significant ($P< 0.01$)

TABLE 17a

SUMMARY OF $C_{22:1}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK (Y) AND ADIPOSE TISSUE (A) FOR ALL PERIODS

Strain	Location	Low Fat	Soybean Oil	Rapeseed Oil	Mean
Pe	Y	0	0	1.32	1.32
	A	0	0	4.00	4.00
Sh	Y	0	0	1.13	1.13
	A	0	0	5.72	5.72
Cl	Y	0	0	1.41	1.41
	A	0	0	2.39	2.39
Mean	Y	0	0	1.29	1.29
	A	0	0	4.04	4.04

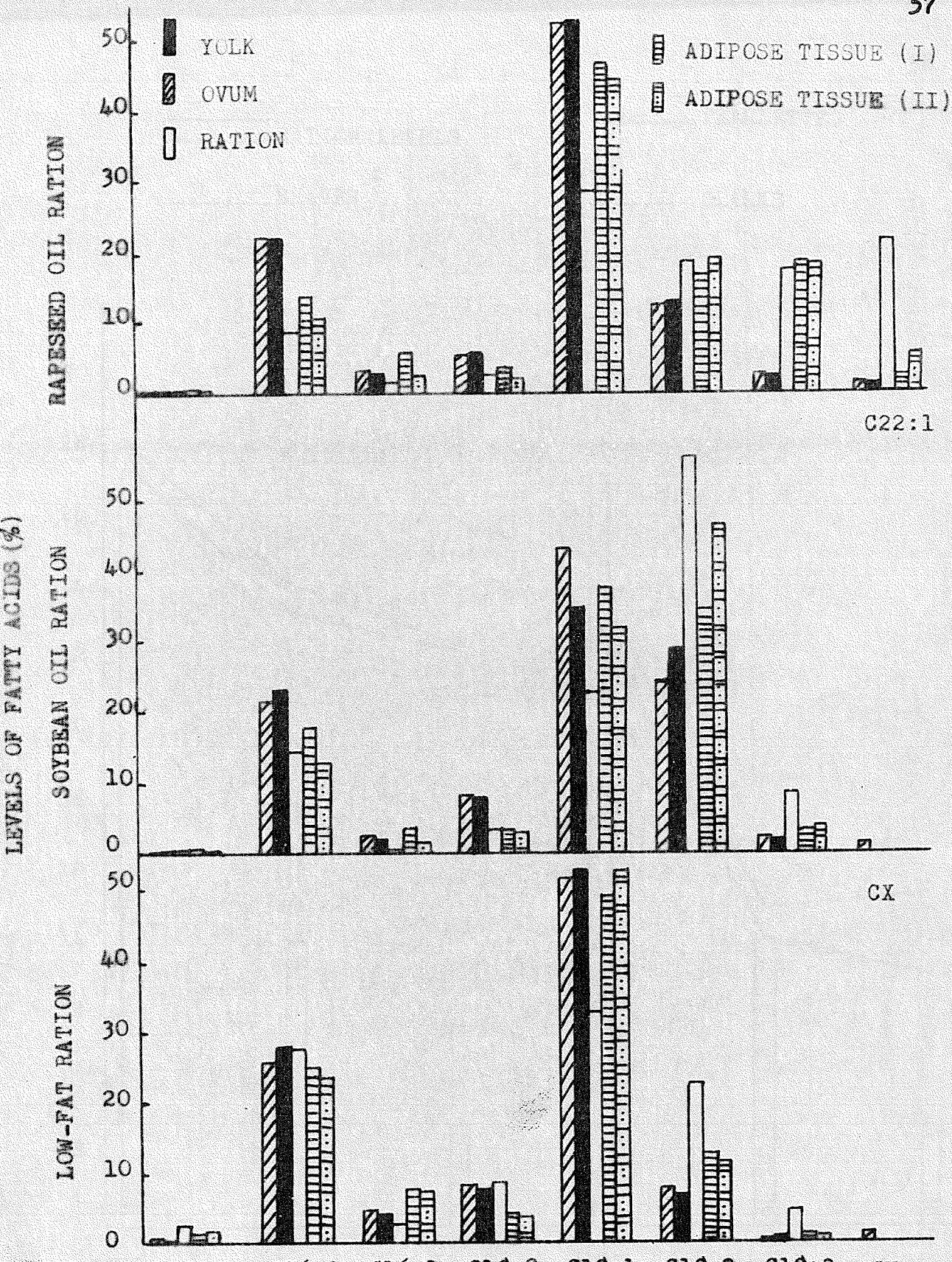

FIGURE 1

COMPOSITION OF FATTY ACIDS IN RATIONS, EGG YOLK, GROWING OVA AND ADIPOSE TISSUE.

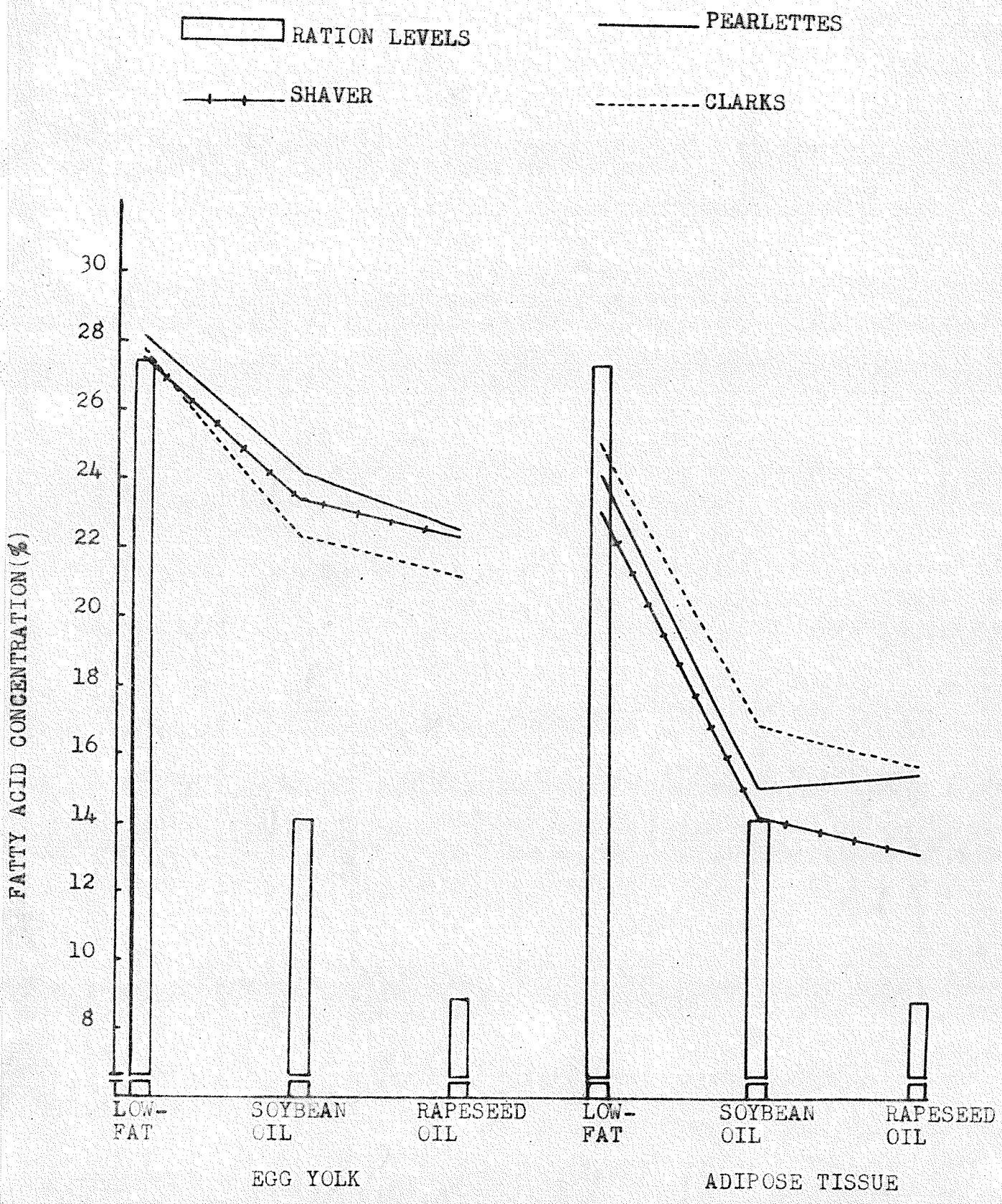

FIGURE 2. PALMITIC ACID CONTENT OF EGG YOLK AND ADIPOSE TISSUE OF THE THREE STRAINS FED DIFFERENT RATIONS

in the case of all fatty acids except $C_{18:2}$. This probably reflects an increase in the magnitude of response to variations in dietary fatty acids as the experiment progressed (Tables 10b, 18b and Figure 1). However, data in Table 8 and Table 9 show that changes of each fatty acid in egg yolks as the experiment progressed were not as great as changes in adipose tissue. Significant ($P<0.01$) ration x period interactions for C_{18}, $C_{16:1}$, $C_{18:1}$ and $C_{18:3}$ content of egg yolk lipidsindicate that changes of these fatty acids were not consistent with time on experiment. For example, the content of $C_{18:1}$ in eggs from hens fed the low-fat diet tended to increase with time, but the reverse trend was observed in eggs from hens fed the soybean oil ration.

Influence of Strains on the Fatty Acid Composition of Egg Yolk Lipids

Strain variation in the content of C_{16}, C_{18}, $C_{18:2}$, $C_{18:1}$ and $C_{22:1}$ were highly significant ($P<0.01$). The level of C_{16} in eggs produced by the Pe strain was higher than that of the other strains regardless of ration treatments. Oleic acid content was highest in eggs of Cl strain and lowest in Sh strain, but intermediate in Pe strain, irrespective of ration treatments (Figure 3 and Table 14b). In the case of the low-fat diet, there was little variation among strains in $C_{18:2}$ or $C_{18:3}$ content of

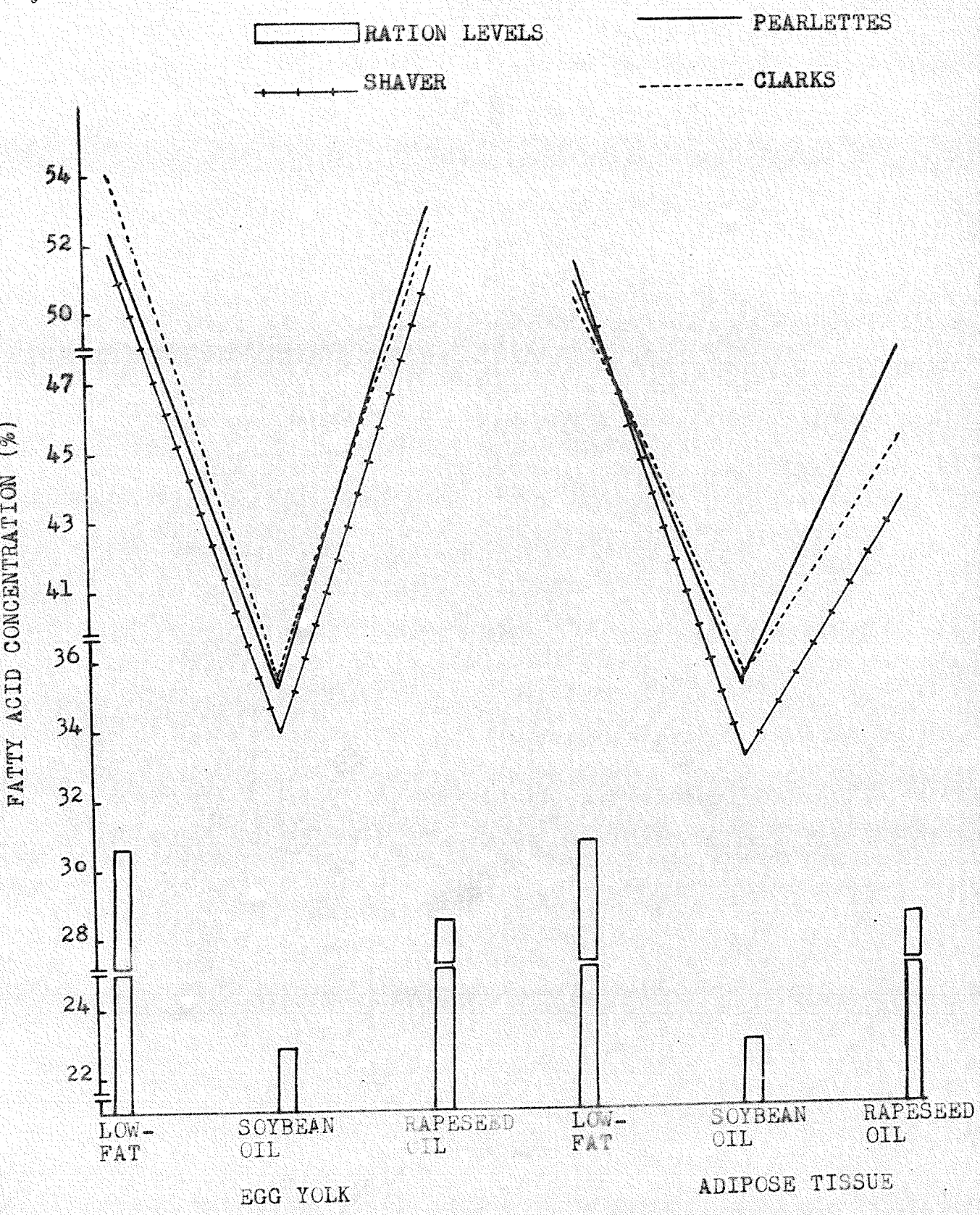

FIGURE 3. OLEIC ACID CONTENT OF EGG YOLK AND ADIPOSE TISSUE OF THE THREE STRAINS FED DIFFERENT RATIONS

yolk (Figures 4 and 5); all strains behaved similarly by depositing a low level of these fatty acids in yolk fat. When considerable $C_{18:2}$ was supplied by soybean oil, the Sh and Cl strains had the ability to deposit a higher level of $C_{18:2}$ in egg yolk than Pe strain. A similar trend was observed with respect to $C_{18:2}$ when the rapeseed oil ration was fed, but not in the case of $C_{18:3}$ (Figure 5). These data illustrate a large variation in the response of different strains to various ration treatments. Erucic acid was not deposited at a high level in the yolk of any strain, yet strain differences ($P < 0.01$) (Table 17b) were noticed. It appeared that strain Sh was able to deposit a considerably higher percentage of $C_{22:1}$ in yolk lipid than the other two strains.

Significant ($P < 0.01$) strain x ration interactions were noted with regard to $C_{16:1}$, $C_{18:2}$, $C_{18:3}$ and $C_{22:1}$ content of yolk fat (Tables 12b, 15b, 16b and 17b). This indicates that variation in the proportions of fatty acids in different rations had varying effects among the three strains. Although strains Sh and Cl responded to marked changes in dietary $C_{18:3}$ level by depositing varying amounts of this fatty acid in yolk fat, strain Pe did not follow a consistent pattern (Figure 5). This serves as an example of the strain x ration interaction. A partial lack of con-

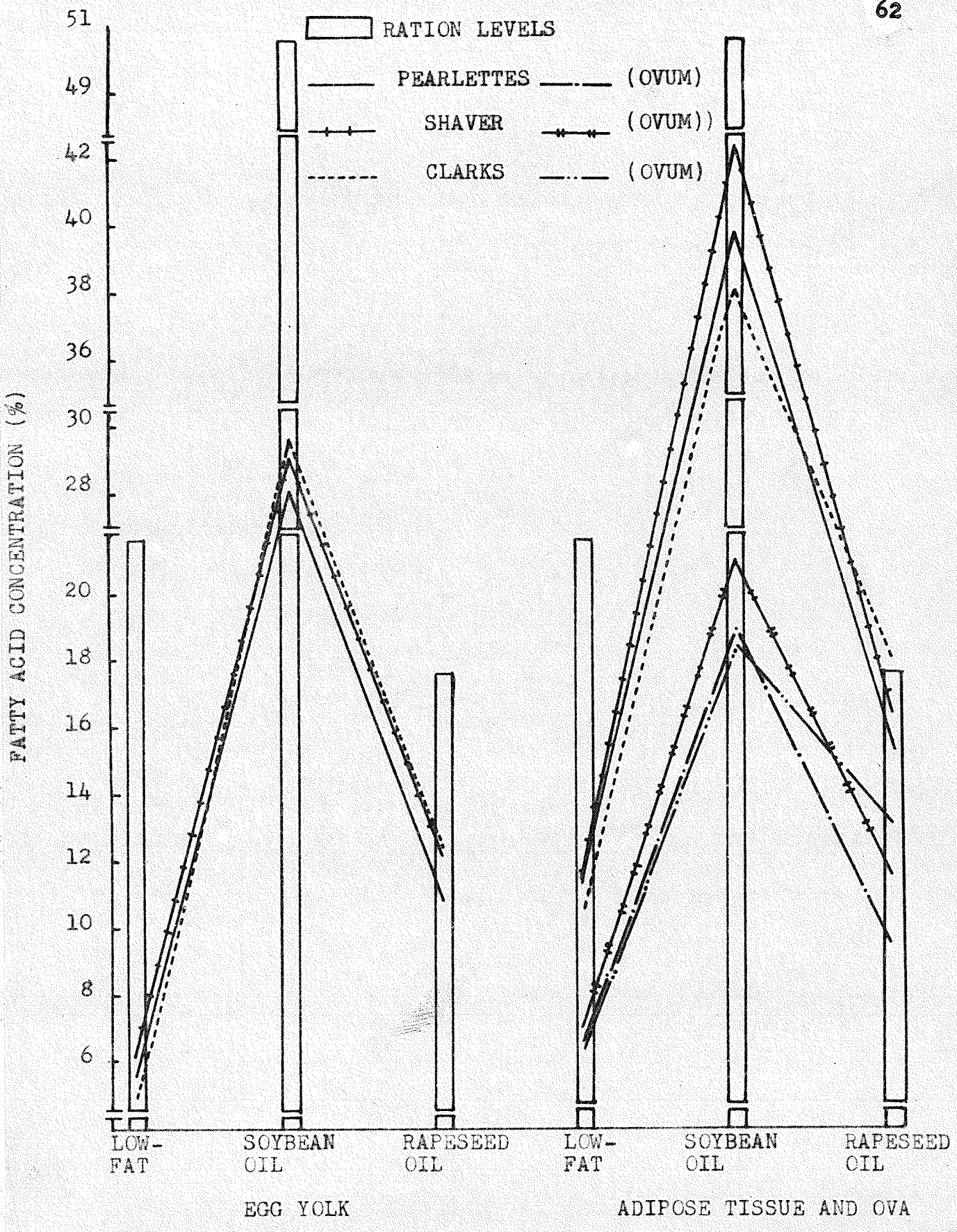

FIGURE 4. LINOLEIC ACID CONTENT OF EGG YOLK, ADIPOSE TISSUE AND OVA OF THE THREE STRAINS FED DIFFERENT RATIONS

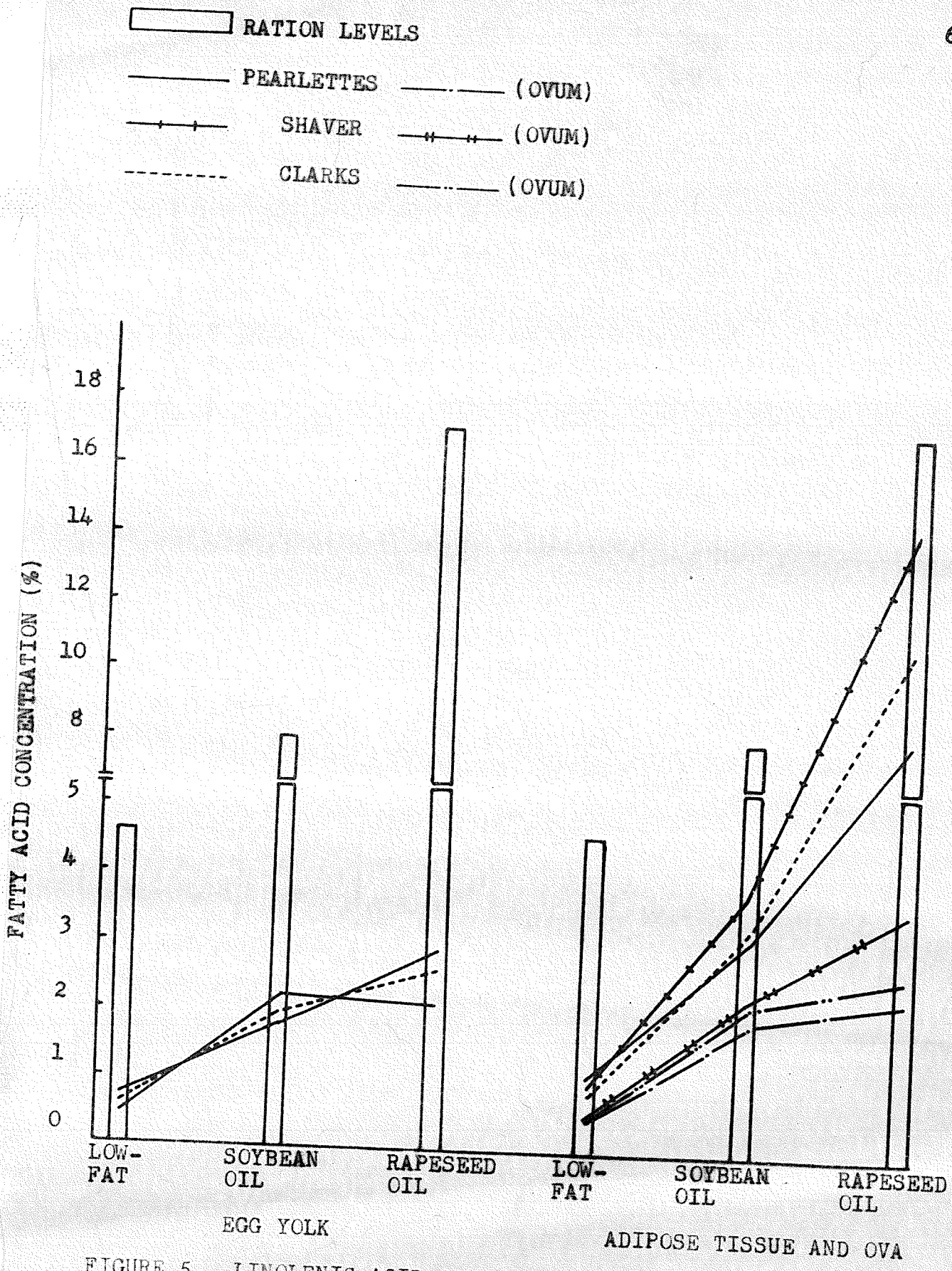

FIGURE 5. LINOLENIC ACID CONTENT OF EGG YOLK, ADIPOSE TISSUE AND OVA OF THE THREE STRAINS FED DIFFERENT RATIONS

sistency of strain with time on experiment was indicated by the significant ($P < 0.01$) strain x period interaction (Table 16a).

Effect of Dietary Fats on the Fatty Acid Composition of Adipose Tissue Lipids

Effects of dietary fats on fatty acid composition of adipose tissue were noted (Table 10b through 17b). In general, the pattern of fatty acid composition reflected that of the dietary source (Figure 1). Hens fed the low-fat diet maintained a higher concentration of C_{18}, C_{16} and C_{14} fatty acid in adipose tissue than those fed high-fat diets. As compared with egg yolk lipid composition, the level of C_{14} was higher while C_{16} and C_{18} level was lower in adipose tissue, although in both cases they were proportional to that of diet. Linoleic and linolenic acids comprised a much larger proportion of the adipose tissue than that of yolk. In hens fed the soybean oil diet, which was high in $C_{18:2}$ content, adipose tissue possessed about 40% of $C_{18:2}$. When hens were fed the rapeseed oil ration, the $C_{18:2}$ content of adipose tissue was 17.8%, nearly proportional to that level in the dietary fat, but higher than that observed in egg yolk. Hens fed the low-fat diet also had a considerably higher concentration of $C_{18:2}$ (11.8%) in adipose tissue than in egg yolk fat. Levels of $C_{18:3}$

in adipose tissue were high, especially in those hens receiving the rapeseed oil diet. In the latter case, the tissue level of $C_{18:3}$ tended to approach the dietary level as time of feeding was prolonged. A marked difference between the soybean oil and rapeseed oil rations was noted in the amount of $C_{18:3}$ of adipose tissue (Table 16a). This was in contrast to only a slight difference between these treatments noted with regard to the same fatty acid in yolk lipid (Table 16a). Erucic acid ($C_{22:1}$) was not as readily incorporated into depot fat as other fatty acids, but was deposited at higher levels as the trial progressed, and was consistently higher in adipose tissue than in yolk fat.

A significant ($P < 0.01$) effect on dietary fatty acids of adipose tissue was observed. Data in Table 9 and Figure 1 illustrate the period effects whereby changes in fatty acid composition of adipose tissue were different for hens receiving the low-fat than for those receiving high-fat diets. Adipose tissue of hens fed the low-fat ration, gradually decreased in C_{16}, $C_{18:2}$ and $C_{18:3}$ content, while $C_{18:1}$ simultaneously increased. On high-fat diets, the concentrations of C_{16}, $C_{16:1}$ and $C_{18:1}$ were higher than the dietary levels, and low levels of $C_{18:2}$, $C_{18:3}$ and $C_{22:1}$ were found during the first month of feeding. As the trial progressed

(Period I and II), levels of C_{16}, $C_{16:1}$, C_{18} and $C_{18:1}$ decreased markedly while there was a distinct increase in $C_{18:2}$, $C_{18:3}$ and $C_{22:1}$ (Table 9). By Period II, the composition of adipose tissue of hens fed high-fat diets tended to resemble that of the dietary fat.

Influence of Strains on the Fatty Acid Composition of Adipose Tissue

Strain differences were significant ($P < 0.01$) in the content of C_{16}, $C_{18:1}$, $C_{18:3}$ and $C_{22:1}$ in adipose tissue (Tables 11b, 14b, 16b and 17b). In single analysis of variance data obtained in the last period which is more representative than data of the first period as to the effect of strain and ration, strain differences in the content of $C_{18:1}$ and $C_{16:1}$ were also significant ($P < 0.01$). As was observed in egg yolk lipids, the influence of strain on the fatty acid composition of adipose tissue was not always the same among strains of hens receiving the same ration. Fatty acids that differed significantly amongst strains with respect to egg yolk fat did not necessarily differ in the case of adipose tissue. For example, the level of C_{18} and $C_{18:2}$ in egg yolk lipid was influenced markedly ($P < 0.01$) by strain differences but was not affected significantly by strain differences in so far as adipose tissue was concerned.

On the contrary, linolenic acid content which was influenced significantly by strain differences in adipose tissue, was not significantly affected by strain variation in the case of egg yolk lipid. Significant ($P < 0.01$) strain x ration interactions were found in the case of $C_{18:1}$, $C_{18:3}$ and $C_{22:1}$ (Tables 14b, 16b and 17b), and significant ($P < 0.01$) strain x period interactions were observed with $C_{18:1}$ and $C_{18:3}$ (Table 14b and 16b). As a whole, when observing the general trends of the responses of these fatty acids (C_{16}, $C_{18:1}$, $C_{18:2}$ and $C_{18:3}$) for each strain regardless of ration effects, they were not always the same for egg yolk and adipose tissue (Figures 2 - 5). However, when the comparisons were limited to strains Pe and Sh, it was found that the trends of fatty acid in yolk lipid and adipose tissue within a strain were similar. For example, linoleic acid content of strain Sh was higher than that of the Pe (Figure 4) while the opposite was true for $C_{18:1}$ and C_{16} (Figures 2 and 3). An exception to these trends was observed in the case of $C_{18:3}$ in yolk and adipose tissue. In this instance, a significant strain x ration interaction resulted from an inconsistent response of strains Pe and Sh to the three ration treatments. If these comparisons were made for strain Cl and the above two strains, they varied greatly, and a highly significant strain x ration interaction was ob-

served for almost all the fatty acids in both yolk and adipose tissue.

Influence of Dietary Fats and Strains on Fatty Acid Composition of Growing Ova in Ovary

Significant ($P < 0.01$) ration effects for all the fatty acids in growing yolk were noticed, except for the unidentified fatty acid (Cx) which occurred in all ova, irrespective of ration treatments. There were significant ($P < 0.01$) strain differences in the content of C_{16}, C_{18}, $C_{18:2}$ and Cx* (Table 18a). The strain x ration interactions for concentration of $C_{18:1}$ and $C_{18:2}$ were also significant ($P < 0.01$). Although considerable differences were observed for all fatty acids with change in ova size (periods), these differences were not significant. The reason for the non-significant differences of fatty acid composition between size of ova could probably be due to overlapping of categories of ova size, since there was no absolute distinguishing partition between these ova. When each fatty acid in growing yolk was compared with the corresponding fatty acid in the mature egg, there was no difference in the saturated acids C_{14} and C_{18}, but the concentration of $C_{16:1}$ was slightly higher in growing yolk. The level of $C_{18:1}$ was the

*Cx refers to an unknown fatty acid.

TABLE 18a

FATTY ACID COMPOSITION (AS % OF TOTAL METHYL ESTERS) OF TOTAL LIPIDS IN GROWING OVA

Fatty Acid	Period	Low-Fat Ration			Soybean Oil Ration			Rapeseed Oil Ration		
		Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
C_{14}	I	0.6±0.2[a][b]	0.6±0.1	0.5±0.2	0.6±0.0	0.2±0.1	0.4±0.4	0.4±0.1	0.5±0.1	0.4±0.0
	II	0.5±0.1	0.6±0.2	0.5±0.0	0.5±0.0	0.2±0.1	0.3±0.1	0.3±0.1	0.3±0.0	0.3±0.2
	III	0.6±0.0	0.9±0.5	0.6±0.1	0.3±0.1	0.4±0.2	0.4±0.2	0.4±0.1	0.3±0.0	0.3±0.1
C_{16}	I	25.3±0.5	25.0±1.4	24.8±0.5	22.0±0.7	21.8±0.3	22.3±1.9	22.8±1.8	22.0±1.7	20.5±0.1
	II	25.7±0.4	26.8±0.9	24.6±0.6	21.3±1.4	21.5±1.6	20.1±0.9	22.2±0.7	22.2±1.5	22.1±0.8
	III	25.5±0.1	26.0±0.6	24.5±2.0	22.0±0.5	22.7±0.8	20.4±0.5	23.3±0.7	22.5±0.6	21.7±0.7
$C_{16:1}$	I	4.3±1.5	4.2±0.0	4.3±0.8	3.0±0.9	2.3±0.3	3.2±0.4	2.5±1.0	3.2±0.4	3.0±0.7
	II	4.1±0.4	4.6±0.4	5.1±0.2	2.6±0.3	1.8±0.0	2.9±0.3	2.5±0.6	3.6±1.3	2.9±0.5
	III	5.3±1.8	5.1±0.1	5.0±0.4	2.6±0.6	2.9±1.1	3.1±0.5	2.4±1.0	3.9±0.5	3.1±0.7
C_{18}	I	8.8±1.0	8.3±0.7	8.8±1.5	9.0±0.7	7.8±1.3	9.8±1.0	5.6±1.7	6.1±0.3	6.1±2.0
	II	8.7±1.5	7.3±0.7	7.4±0.1	8.7±0.0	6.7±2.4	8.1±0.5	7.0±0.3	4.8±0.7	5.3±0.9
	III	7.7±0.0	7.7±1.0	7.9±0.4	8.7±0.6	6.6±0.7	7.8±0.9	6.3±1.1	5.7±0.0	4.7±1.2
$C_{18:1}$	I	50.2±1.6	51.6±1.1	51.7±0.9	41.9±0.2	42.8±1.5	43.9±3.1	53.6±0.2	51.7±2.8	51.3±3.5
	II	49.9±3.2	51.7±1.7	53.7±0.1	44.1±0.3	43.8±2.1	44.8±0.7	53.9±1.3	51.4±1.5	51.0±1.0
	III	50.8±1.6	51.3±1.0	52.3±0.6	42.1±0.1	42.4±1.5	43.7±2.9	53.6±1.3	50.1±0.9	52.2±3.2
$C_{18:2}$	I	7.7±1.0	8.3±0.8	7.9±0.2	19.5±0.6	21.9±0.7	17.3±2.9	10.6±0.8	12.3±2.4	14.4±0.7
	II	7.9±0.6	7.4±1.8	6.9±2.2	20.1±1.5	21.7±1.3	20.4±0.5	10.9±0.5	12.8±1.8	14.6±0.1
	III	7.7±0.4	8.5±2.4	8.0±0.1	19.9±0.3	22.0±2.7	20.8±1.0	10.9±1.1	12.7±2.1	14.1±1.2

TABLE 18a (Continued)

Fatty Acid	Period	Low-Fat Ration			Soybean Oil Ration			Rapeseed Oil Ration		
		Pe	Sh	Cl	Pe	Sh	Cl	Pe	Sh	Cl
$C_{18:3}$	I	0.3±0.2	0.7±0.4	0.3±0.1	1.1±0.2	1.6±0.0	1.6±1.5	1.5±0.6	1.4±0.4	1.2±0.2
	II	0.5±0.1	0.3±0.1	0.5±0.0	1.2±0.5	1.4±0.7	1.5±0.3	0.9±0.2	1.9±0.3	1.4±0.3
	III	0.2±0.0	0.3±0.3	0.2±0.0	1.5±0.4	1.6±0.0	1.9±0.1	0.9±0.6	1.8±0.2	1.5±0.6
Cx	I	2.7±0.4	1.3±0.3	1.7±0.2	2.5±0.1	0.9±0.5	1.1±0.3	1.7±0.4	1.2±0.0	1.8±0.7
	II	1.8±0.2	1.1±0.3	1.2±0.2	1.2±1.6	1.6±0.1	1.3±0.3	1.5±0.2	1.1±0.4	1.1±0.1
	III	2.1±0.6	0.3±0.5	1.4±0.5	2.0±0.2	1.0±0.2	1.4±0.1	1.4±0.5	0.9±0.2	1.2±0.5

Cx = unknown fatty acid which has a similar retention time to that of erucic acid.
[a]Mean of 2 duplicates.
[b]Standard deviation.

same in mature and growing yolk from hens fed either low-fat or the rapeseed oil diet, but was much higher in immature ova of hens fed the soybean oil ration. The concentration of $C_{18:2}$ and $C_{18:3}$ was slightly higher on the low-fat diet as compared with high-fat rations. The level of unidentified fatty acid (Cx) tended to decrease with increasing size of ova.

DISCUSSION

The inclusion of soybean or rapeseed oil in laying hen rations exerted marked effects on feed consumption, feed efficiency, rate of egg production as well as the weight of individual egg and yolk. Generally, feeding rations containing 14% soybean or 14% rapeseed oil decreased feed consumption in comparison to the low-fat ration. In the case of soybean oil, the decrease in feed consumption was in proportion to the higher energy density of the ration, indicating that the hen eats primarily to satisfy her energy requirement. This is in accord with the observation by Hill and Dansky (1954), that chicks eat to meet their energy requirements, while protein level, if adequate, has little effect on feed consumption. MacIntyre and Aitken (1957) reported that neither high energy nor high protein had any influence on rate of egg production, egg weight or specific gravity of the eggs, but feed consumption and feed per dozen eggs were markedly decreased by increasing the energy content of the diet. In subsequent experiments where production averaged 70% over the year, they found that feed required per dozen eggs increased approximately 11% per 100 calories decrease in productive energy per pound of feed. Hill et al. (1956) showed that gross efficiency of egg production as

measured by feed required per dozen eggs was markedly influenced by energy level. Relative to a ration containing 930 calories of productive energy per pound, a decrease in energy concentration of 100 calories per pound increased feed required by approximately 12%. Increasing energy level by the use of fat (tallow) reduced feed required per dozen eggs at a rate of two per cent for each one per cent of added fat.

The present findings also show that hens fed either a low-fat diet or high soybean oil ration produced the same total weight of eggs even though they differed in the rate of egg production. Although hens fed the low-fat ration produced more eggs than hens fed 14% soybean oil, the eggs were smaller and as a result total weight of eggs produced per hen-day was the same for both ration treatments. The differences between these two ration treatments in average egg weight was not due to difference in intake of major nutrients, since feed intake was in proportion to ration energy level and ratios of energy to nutrients were the same in both ration treatments. Thus, the difference in egg weight must have been due to replacing a portion of ration carbohydrate with soybean oil. It has been reported that adding $C_{18:2}$ to low fat laying hen rations increased egg weight (Marion and Edwards, 1964). However, whether or

not this occurred in the present study could not be determined.

Beare (1961) presented data showing that the inclusion of rapeseed oil in rations depressed food intake of rats, and the degree of depression was directly related to the level of rapeseed oil in the diet. Earlier work (Beare et al. 1959) indicated that erucic acid ($C_{22:1}$), a major constituent of rapeseed oil, was slowly absorbed by the animals and that this may be the factor that depressed feed intake. Beare et al. (1959) found that feed intake was impaired and weight gain decreased when ethyl erucicate was added to rat rations. This evidence suggested a direct influence of $C_{22:1}$ on feed intake. However, a later study by Beare et al. (1963) showed that a relatively low level of saturated fatty acid (C_{16}) together with a high level of erucic acid were major factors in rapeseed oil that caused the depression of feed intake. Earlier, Beare (1961) showed that rats fed a diet containing 20% rapeseed oil continued to reproduce, but they had fewer and smaller offspring than rats fed a normal diet. In the present study hens receiving a diet containing 14% rapeseed oil consumed less feed and produced fewer and smaller eggs than hens fed low-fat or soybean oil diets. The fact that hens fed 14% rapeseed oil consumed considerably less feed than those fed 14% soybean oil shows that factors other than ration

energy level *per se* exerted an adverse effect in the former case. Not only was feed consumption decreased due to rapeseed oil, but rate of egg production was drastically reduced and egg size was decreased. These concurrent findings indicate that the deleterious effect of rapeseed oil was not due to poor absorption of dietary energy alone, but that metabolism and egg formation *per se* were adversely affected.

The data for egg weight, yolk weight, feed consumption, feed efficiency and egg production indicate that ration effects on these variables were more important and obvious than strain effects. However, this does not mean that strain differences were not significant. On the contrary, the present study shows that strain effects play an important role in maximum egg production. For instance, Sh strain was the best among the three strains studied in utilization of feed for egg production, and produced the heaviest eggs among the three strains. On the other hand, strain Cl had a lower feed efficiency and rate of egg production regardless of ration treatments. Similarly, strain effects on egg weight and egg components have also been demonstrated by several workers. May and Stadelman (1960) conducted an experiment using five strains of hens (three Leghorn strains, one New Hampshire strain and a Hoosier

White strain), and observed that strain of hen significantly influenced per cent moisture and protein in eggs. In addition, mean egg weights varied from 59.6 g. to 62.2 g. among different strains. Arroyave et al. (1957) detected significant differences among nitrogen, ash, phosphorus, vitamin A and carotene contents of eggs from five breeds of hens. Earlier, Farnsworth and Nordskog (1955) presented data showing important breed and strain differences in egg qualities (egg weight, shell color, shell thickness, albumen height and yolk color) and suggested that considerable improvement in these qualities were possible by mass selection of hens. Recently, Marion et al. (1965) found that eggs from five different stocks of hens differed significantly in weight, per cent of shell, yolk, moisture and lipid, as well as fatty acid content. The above reports correspond with the current findings that strain differences play an important role for egg production (size, rate and quality).

In addition, the significant strain x ration (S x R) interactions observed in the case of egg production and feed efficiency shows that there are differences among strains in response to various ration treatments. Although these strain x ration interactions were observed, their relative importance, based on magnitude of the differences

resulting from the interaction effects, appear to be of minor practical significance.

Fatty acids in animal tissue and products may be derived endogenously by synthesis (lipogenesis) through interconversion of fatty acids within the body, or they may be obtained exogenously from the diets. In the present study, hens fed a low-fat ration (two per cent tallow) were able to produce normal eggs at a regular rate. Therefore, the majority of the egg fat produced by these hens must have been derived by de novo synthesis from carbohydrate and other nutrients. The relatively high levels of C_{14}, C_{16}, $C_{16:1}$ and $C_{18:1}$ in eggs of hens fed low-fat diet, indicates that mostly monounsaturated and saturated fatty acids were synthesized from carbohydrate. This is in agreement with the work of Insull et al. (1958) who found that monounsaturated and saturated fatty acids in human milk were derived by endogenous synthesis from carbohydrate precursors. Wheeler et al. (1959) showed that eggs from hens fed a stock ration had relatively high levels of C_{16} and $C_{18:1}$, and Feigenbaum and Fisher (1959) observed that eggs from hens fed a "fat-free diet" contained a large amount (48%) of $C_{18:1}$ in yolk. In the latter case, $C_{18:1}$ concentration in yolk was higher than that observed when rations containing various sources of fats were fed. These latter

reports show that high levels of monounsaturated fatty acids were found in yolks of hens fed low-fat diets in which case biosynthesis of $C_{18:1}$ would be required.

In the present investigation, levels of essential fatty acids (EFA) ($C_{18:2}$ and $C_{18:3}$) diminished gradually with time on the low-fat diet. This finding is in keeping with the reports of Reiser (1950a) and Feigenhaum and Fisher (1959) who found that EFA cannot be synthesized from non-fat precursors by the hens. Machlin and Gordon (1962) reported that adult hens were not sensitive to a deficiency of EFA as a result of large reserves of $C_{18:2}$ in adipose tissue. Heald and Badman (1963) found that the onset of laying in the hen was preceded by a large increase of free-fatty acids and phosphoprotein in the plasma. The quantities of these components decreased markedly when laying commenced and never reached a high level again. This suggested that maximum storage of fatty acids in pullets occurred before the first egg was laid. In the current study, the low-fat diet was given to the hens until after 50% egg production was attained. Evidently, these hens had stored considerable quantities of EFA from the pre-experimental ration (practical laying hen diet), and used these stores to maintain the $C_{18:2}$ and $C_{18:3}$ levelsin the egg yolk. Eggs produced after six months of feeding the low-fat diet still

possessed considerable $C_{18:2}$ (5 - 7%) and $C_{18:3}$ (0.5 - 1%). It would probably take a long time on a low-fat diet before the EFA status of the hen would be depleted sufficiently to affect normal egg production.

The common de novo synthesis of fatty acids in the animal body is not always constant, but is influenced by the dietary fat; the more fat included in the diet, the slower is the rate of fatty acid synthesis from non-fat sources in the liver or adipose tissue (Hill et al. 1958). Obviously, dietary fatty acids tend to inhibit fat synthesis in the animal body; a negative feed back control circuit. Thus, the role of dietary fatty acids in determining yolk and adipose tissue fat composition cannot be ignored, particularly when a high level of fat is included in the ration. The results herein indicate that the primary effect of ingested lipid in hens was a modification of major fatty acid composition in adipose tissue and yolk fat (Figure 1). Also, there is an apparent direct deposition of some unaltered dietary fatty acids in both egg yolk and adipose tissue. This finding corroborates the previous reports of Cruickshank (1934), Reiser (1950a), Feigenbaum and Fisher (1959), Wheeler et al. (1959) and Chen et al. (1965) that egg fat composition could be modified by dietary fat. The reason

for the preferential incorporation of dietary fatty acids in animal tissue could be due to the fact that the lipid fraction is more efficient, energetically speaking, in maintaining and increasing the level of egg and tissue lipids than lipogenesis from other nutrients.

The actual contribution of dietary fats to tissue fatty acid composition varies considerably from one tissue to another, from one lipid class to another, and also on physiological conditions of the animal. In the current study, when a high level of $C_{18:2}$ was provided in the diet, a higher concentration of this acid in egg yolk or adipose tissue was accompanied by low levels of $C_{18:1}$ and $C_{16:1}$. Reiser (1950a), Wheeler *et al.* (1959) and Horlick and O'Neil (1958) observed the same phenomenon. This relationship was also noted by Mohrhauer and Holman (1963a) in epidiedymal fat of rats. They theorized that the rats were attempting to maintain a minimal degree of total unsaturation of tissue fat. In the present study, the above relationship probably indicates the degree of inhibition of lipogenesis by dietary fat. The readily increasing level of $C_{18:2}$ observed in the current study may be due to its relative stability and the ease with which it can be deposited in the animal body as compared with other fatty acids. This fatty acid, not being a precursor of saturated or monoenoic fatty acids, tends to

replace the fatty acids of endogenous origin. Bottino *et al.* (1965), using isotope tracers, found that feeding linolenic acid reduced fatty acid synthesis to very low levels and that $C_{18:2}$ was not converted to other fatty acids but tended to increase in the animal body at the expense of fatty acids of endogenous origin.

Deposition of $C_{18:3}$ in yolk fat of eggs from hens receiving soybean oil was less efficient than was that of $C_{18:2}$. This agrees with data presented by Fisher and Leveille (1957) who also observed a low level of $C_{18:3}$ in egg yolk. The deposition of this fatty acid (2.5%) was less in hens fed the rapeseed oil, in spite of the fact that the ration contained 17.3% of this acid. Wheeler *et al.* (1959) obtained similar results when a diet, containing 30% linseed oil was fed (the fat contained 58.3% $C_{18:3}$). They found that only 13.5% of the $C_{18:3}$ entered into the egg yolk. Chen *et al.* (1965) using 10% linseed oil (58.9% $C_{18:3}$) obtained less than 12% of this acid in the egg. A more specific study was conducted by Murty and Reiser (1961) where graded levels of pure $C_{18:2}$ and $C_{18:3}$ were fed. They found that when an equal amount of dietary $C_{18:2}$ and $C_{18:3}$ was supplied to hens, deposition of $C_{18:3}$ in yolk was only about half as much as $C_{18:2}$ (12.06 and 24.9 respectively). Murty and Reiser (1961) believed that these differences in

preferential deposition of $C_{18:2}$ were due to metabolic alterations of $C_{18:3}$ (desaturation, interconversion, etc.). Reiser (1951) fed non-conjugated trienoic acid (Trilinolenic or linolenic) to hens which had been fed a fat-free ration for 19 and 27 weeks, and found that the amount of $C_{18:3}$ in neutral fat of yolk increased initially and then decreased rapidly to a very low level and eventually disappeared. This was accompanied by an increase in polyunsaturated acids having two to six double bonds. Reiser (1950) suggested that the low efficiency of utilization of $C_{18:3}$ was due to its rapid conversion to other fatty acids but not preferential oxidation. Mohrhauer and Holman (1963b) observed that $C_{18:3}$ competes with $C_{18:2}$ and $C_{18:1}$ in the formation of polyunsaturated acids. Linolenic acid acts as a more favorable substrate than either $C_{18:2}$ or $C_{18:1}$. The results of the present study do not support this view since there was no increase in $C_{18:2}$ at the expense of $C_{18:3}$ observed nor was an accumulation of polyunsaturated ($C_{20:4}$ etc.) fatty acids detected. It appears that preferential oxidation was the cause of low incorporation of $C_{18:3}$ in the egg fat.

The influence of dietary fatty acids on fatty acid composition of adipose tissue was more pronounced than on yolk fat, particularly in the case of $C_{18:2}$ and $C_{18:3}$. Thus, it appears that dietary fatty acids are more readily

deposited directly in depot fat than in yolk. Similar results were obtained by Ostwald *et al.* (1962) who observed 53% $C_{18:2}$ in rat adipose tissue when 10% safflower oil was fed for three weeks. Beare (1964) reported that when oils high in $C_{18:2}$ were fed, the concentration of this acid in tissue varied not only with dietary level, but also with its relative proportion to other fatty acids, and that when the fat intake was high enough to render lipogenesis of little consequence, the level of $C_{18:2}$ in tissue tended to approach that of dietary fat. The present results are in agreement with the above findings in that the $C_{18:2}$ and $C_{18:3}$ were easily incorporated into adipose tissue, although the deposition of $C_{18:3}$ was less efficient than $C_{18:2}$. The dissimilarities in fatty acid composition of yolk and adipose tissue suggests different pathways of fat deposition in depot and egg fat.

In the present investigation, the levels of some fatty acids (C_{16}, $C_{16:1}$, C_{18} and $C_{18:1}$) in yolk or adipose tissue were higher than that present in the diet (Figure 1). This indicates the occurrence of lipogenesis of fatty acids from non-fat nutrients or a preferential deposition of the fatty acid in yolk and adipose tissue. It was also observed that the levels of monounsaturated ($C_{16:1}$ and $C_{18:1}$) acids decreased simultaneously with an increase in $C_{18:2}$ and $C_{18:3}$ as the experiment progressed into the third period.

This may indicate that the decrease in the levels of monounsaturated fatty acids was due to an inhibition of lipogenesis and an accompanying increase in deposition of $C_{18:2}$ and $C_{18:3}$ of dietary origin. Similar observations were made by Bottino *et al.* (1965) who reported that there was little or no synthesis of fatty acids in rats fed high levels of fat and this inhibition of endogenous synthesis was reduced when rats received low levels of fat. The results (Figure 1) also indicate a possible relationship between $C_{18:2}$ and $C_{18:1}$ involving *de novo* synthesis and participation of dietary fat in the formation of tissue fat in hens. Increased deposition of dietary fat (mainly $C_{18:2}$) was accompanied by a decreased *de novo* synthesis (mostly $C_{18:1}$). Increased level of $C_{18:2}$ in both yolk and adipose tissue with duration of ration treatments was followed by a relative decrease in $C_{18:1}$ content. In adipose tissue, reflection of much higher level of dietary $C_{18:2}$ was not merely accompanied by the distinct decrease of $C_{18:1}$ alone, but also a decrease in C_{18}, C_{16} and $C_{16:1}$. It appears that participation of dietary fat in the formation of egg yolk, ova, and adipose tissue was related to the influence of $C_{18:2}$ on synthesis and subsequent deposition of endogenous fatty acids. Its inhibition of *de novo* synthesis was first indicated by the

decrease of $C_{18:1}$ followed by C_{16}, $C_{16:1}$ and C_{18}, as the degree of inhibition by dietary fat ($C_{18:2}$) was further intensified.

A high level of $C_{22:1}$ (21%) in the ration resulted in the occurrence of a low level of this acid in the egg yolk (1.3%), and in adipose tissue (4%). Sell and Hodgson (1962) found 6.08% $C_{22:1}$ in adipose tissue of chicks fed eight per cent rapeseed oil (31.5% $C_{22:1}$) for eight weeks. Beare (1961) reported that the $C_{22:1}$ content of carcass fat in female rats was 11% after a diet containing 20% rapeseed oil was fed. Milk fat from rats fed rapeseed oil contained 15% of this acid. As a percentage of total fatty acids, the latter results are higher than the level found in egg yolk in the present experiment. These differences may be only qualitative and not necessary quantitative, or they may be attributed to differences in fat metabolism between the two species. The extremely low level of $C_{22:1}$ in adipose tissue may be due to the initial presence of "normal" fatty acids at the start of experiment and/or the non-biosynthesis of erucic acid in contrast to the continuous synthesis of all the other fatty acids such as C_{16}, $C_{16:1}$, C_{18} and $C_{18:1}$. Either one or both of the above would have a diluting effect on erucic acid concentration in tissue. It is also possible that a preferential catabolism (or interconversion) of

$C_{22:1}$ occurred, which would reduce the amount of this fatty acid available for deposition. It is doubtful that depressed feed intake or poor absorption of the dietary fat from the rapeseed oil ration was of importance in the resulting fatty acid composition of tissue. If these factors had a direct effect, then EFA levels in yolk fat and adipose tissue of hens fed rapeseed oil should also have been relatively low.

Strain differences in fatty acid composition of egg yolk lipid have been reported by Marion and Edwards (1964). Based on a study of hens from five different strains fed the same commercial ration, they found that strain differences existed only in the case of $C_{16:1}$, C_{18}, $C_{18:1}$ and $C_{18:2}$. Edwards (1964) presented data indicating that the content of $C_{18:1}$, C_{18}, $C_{18:2}$ and $C_{20:4}$ in yolk differed significantly among strains. He also found that C_{16} and $C_{18:1}$ content of yolk did not differ among strains but varied drastically among individuals within a strain. However, Chen *et al.* (1965) found that the fatty acid composition of egg yolk exhibited by the two different breeds (S.C. White Leghorn and Arkanas Silver) did not differ significantly. Under the conditions of the present study, strain differences in fatty acid composition in egg yolk were noted in the case of C_{16}, C_{18}, $C_{18:2}$ and $C_{22:1}$.

Palmitic acid and $C_{18:3}$ contents were not significantly affected by strain differences, but were affected by a marked strain x ration interaction which may have masked any strain differences with respect to these two fatty acids.

Strain differences in fatty acid composition of egg yolk and adipose tissue were not always consistent (Table 10b - 17b). They varied with type of fatty acid in the diet and strain resulting in strain x ration interaction. Fatty acids such as C_{18} and $C_{18:2}$ which were significantly different in egg yolk of different strains were not similarly affected in the case of adipose tissue. Strain x ration interaction was also not always the same between different locations. For example, a strain x ration interaction was noted in $C_{18:1}$ content of adipose tissue, while in egg yolk, strain x ration interaction was observed with respect to $C_{16:1}$ and $C_{18:2}$. These inconsistancies indicate that the genetic factors affecting fatty acid composition in egg fat and adipose tissue of hens are not simple in nature. If genetics is the factor responsible for control of fatty acid composition, then this regulation is probably of a polygene nature. Normally, quantitative inheritance is controlled by several genes, and their potential influence on the fatty acid composition of various organs within the same animal may not always be the same.

In an investigation of the plasma lipid content in mice, Yamamoto et al. (1963) found that the genetic factors governing the plasma lipid concentration were polygenic and had an over-all additive behavior. However, whether genetic effects on fatty acid concentration in egg yolk and adipose tissue of hens are under a similar control to that of plasma lipid in mice is not clear. Further investigation is needed before a conclusion can be drawn.

Little difference between Pe and Sh strains (both of the White Leghorn breeds) was noted in the current study, but both of these strains differed considerably from the Cl strain. This indicates that differences between strains within breeds are less pronounced than variation between strains from different breeds. If one accepts the concept, that many genes control fatty acid composition, then the logical explanation for the latter could be that variation in the sets of genes between strain of unrelated origin are likely to be greater than those between strains with similar origin.

Edwards (1964) noted definite patterns regarding the fatty acid composition of egg lipids within a strain. For instance, the North Carolina Rhode Island Red egg lipid contained a significantly higher amount of $C_{20:4}$ than other breeds while $C_{18:2}$ (metabolic precursor of $C_{20:4}$) appeared to

be present in the smallest quantities in the breed. Purdue Random Breed Rhode Island Red had the highest quantity of $C_{18:2}$ and lowest quantity of C_{18} as compared with other breeds. Commercial Strain White Leghorns had the next highest quantity of $C_{18:2}$. The current investigation show that in adipose tissue the Sh strain possessed the highest level of both $C_{18:2}$ and $C_{18:3}$ and the lowest concentration of C_{16} and $C_{18:1}$. Pe strain had high quantities of $C_{18:1}$, followed by $C_{18:2}$ and $C_{18:3}$, whereas Cl strain had highest amount of C_{16} followed by $C_{18:3}$ and $C_{18:2}$. All these patterns were found when high fat diets were fed. In the low-fat ration, there was hardly any variation among strains in fatty acid composition. This implies that there were differences in the ability of hens from different strains to utilize dietary fats. The Sh strain probably possesses the highest level of enzyme necessary for incorporation of dietary $C_{18:2}$ and $C_{18:3}$ into body tissue and the <u>de novo</u> synthesis of fat was inhibited to the largest extent, resulting in relatively low C_{16} and $C_{18:1}$ levels. Pe strain deposited dietary $C_{18:2}$ and $C_{18:3}$ in body tissues relatively slowly, but synthesized the largest amount of $C_{18:1}$. Cl strain also was unable to incorporate large quantities of $C_{18:2}$ and $C_{18:3}$ into tissue, but synthesized more C_{16} than any other strain. It was also interesting to note that the Sh strain which produced eggs with the highest content of $C_{18:2}$

was also found to produce the largest eggs among the three strains. This serves as evidence to support the fact that $C_{18:2}$ is important for producing large eggs and agrees with work reported by Jensen *et al.* (1958) and Marion and Edwards (1964). Carew and Hill (1964) suggested that an adequate amount of $C_{18:2}$ was required for maximum efficiency of energy utilization when various fats were supplied to chicks.

The intensity of ration effects on young growing ova were less apparent than in mature egg yolk. Sturkie (1965) reported that in a newly hatched female chick, the ovary may be seen as a small irregular tissue consisting of numerous small ova. Each ovum contains a female germ cell and a small amount of yolk. As the female chick approaches sexual maturity, the immature ova begins growing at a rapid rate. In the chicken, they reach maturity within 9 to 10 days. During the growth period, the yolk material is laid down in concentric rings. Since fat comprises 30-32% of the total yolk weight, it is likely that fatty acids in young ova (before rapid growth) were under predominately strong genetic control and were mostly of endogenous origin. The absence of $C_{22:1}$ in young ova indicates that all the major fatty acids were deposited selectively from adipose tissue into the growing ova during the early growing stage. As its rate of development increases (7 - 11 days prior to ovulation), development

of egg yolk may become more dependent on increased participation of dietary fatty acids. As a consequence, levels of those acids which were originally from endogenous source became diluted with those of dietary origin. Therefore, the fatty acid pattern of ova tends to approach that of dietary fat as the ova grows more mature.

Since $C_{18:2}$ and $C_{18:3}$ were not supplied in the low-fat diet, their content in ova was about the same as in mature egg. However, the $C_{18:2}$ and $C_{18:3}$ content of ova from hens fed the high-fat rations was less than in mature yolks. This indicates that the younger ova were not influenced as much by the dietary fat as were mature yolks. Strain differences in content of C_{16}, C_{18}, $C_{18:2}$ and Cx acids contents of growing ova were observed. A definite pattern was also exhibited by different strains upon consuming various rations (Table 19). It is interesting to note that the patterns of $C_{18:2}$ and $C_{18:3}$ observed in different strains closely resemble that of adipose tissue (Figures 4 and 5). This suggests that the fatty acid composition of growing yolks is closely related to adipose tissue during early development. If this concept is logical, it also provides for a possible identification of the Cx acid. Since Machlin and Gordon (1962) reported that hens have a large reserve of $C_{20:4}$ acid, and also through

the technique of fractionation followed by chromatographic analysis of fatty acids in this study, the occurrence of $C_{20:4}$ has been shown, then it is possible that at this stage of development the Cx acid could be $C_{20:4}$ which enters ova during the early development period. As the ova grow bigger, this fatty acid not being obtained from the diet is diluted by other dietary fatty acids. Consequently, its concentration is too small to be detected by the analytical technique used for the analysis of mature yolk lipid. Also, in ova obtained from hens fed rapeseed oil, the relative position of the Cx and $C_{22:1}$ peaks on the chromatogram was difficult to differentiate and thus the presence of Cx in mature yolks from this treatment was difficult to determine.

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[a]Using the fractionation technique described by Vries, B. D., 1963, fatty acid esters containing this peak (acid) were separated into five fractions according to the number of double bonds and carbon chain length. Subsequent Gas Chromatographic analysis showed that $C_{22:1}$ and $C_{20:4}$ were present and they emerged at the same position on the normal Gas Chromatograph run.

SUMMARY AND CONCLUSIONS

An investigation was made on the effects of strains and breeds and different sources of fats on the fatty acid composition of egg yolk, adipose tissue and immature ova. The criteria used for evaluation were the relative percentage of fatty acids in all these tissues. Strain and ration effects on efficiency of feed utilization and egg production were also studied. Under the conditions and limitations of this study, the following conclusions were drawn:

1. In general, hens eat to satisfy their energy requirements. High energy rations decrease feed consumption and improve feed efficiency. The relative decrease in feed consumption was in proportion to the higher energy density of the ration.
2. Feeding soybean oil had little or no effect on the total quantities of egg produced. Hens fed low fat (low energy) and soybean oil diets produced the same amount of egg per hen day. However, more eggs were produced from hens fed the low-fat diet but were smaller in size than those from the soybean oil diet.
3. Inclusion of 14% rapeseed oil in the ration depressed feed intake severely. Feed efficiency,

rate of egg production as well as size of eggs and yolks were drastically reduced. This suggests that factors other than ration energy level *per se* exerted an adverse effect on these parameters when rapeseed oil was fed.

4. Strain and/or breed are also important in attaining high egg production and feed utilization of laying hens. Among the three strains studied, Sh strain was the best in feed utilization for egg production and produced the heaviest eggs. Strain C1 had the poorest feed efficiency and egg production.

5. Age of hens (periods) had a significant influence on feed consumption and utilization, egg production and yolk weight. Feed efficiency and, rate and quantity of egg production decreased while egg and yolk sizes increased with age.

6. Changes in fatty acid composition in egg yolk and adipose tissue were generally proportional to the respective dietary patterns. Almost all of the fatty acids in yolk fat and adipose tissue respond to changes in dietary fats. In comparison with feeding the low-fat ration,

feeding rations containing 14% soybean oil or 14% rapeseed oil caused marked increases in $C_{18:2}$ and $C_{18:3}$ content of tissues. The increases in $C_{18:2}$ and $C_{18:3}$ in these tissues were accompanied by simultaneous decreases in $C_{18:1}$ and, in some cases C_{16} or $C_{16:1}$.

7. Dietary fatty acids, particularly $C_{18:2}$ and $C_{18:3}$, were more readily deposited directly in the adipose tissue than in yolk or ova.
8. Deposition of $C_{22:1}$ was observed. The level found in yolk and adipose tissue increased with duration of the experiment and was consistently higher in adipose tissue than in yolk fat.
9. Eggs and adipose tissue resulting from feeding the low-fat diet possessed relatively high levels of C_{14}, C_{16}, $C_{16:1}$ and $C_{18:1}$ which suggests the preferential <u>de novo</u> synthesis of these acids from non-fat precursors.
10. There were significant strain differences in the content of C_{16}, C_{18}, $C_{18:2}$, $C_{18:1}$ and $C_{22:1}$ in egg yolk, while strain differences occurred in C_{16}, $C_{18:1}$, $C_{18:3}$ and $C_{22:1}$ in

adipose tissue and C_{16}, $C_{18:1}$, $C_{18:2}$ and Cx in ova. These inconsistencies among tissues suggest that factors controlling the composition of fat could be of a polygene nature.

11. Variation in fatty acid composition between strains Pe and Sh were less pronounced than differences between Cl strain and Pe and Sh, indicating that less variation exists between strains of related origin than between strains of distinctly different origin.

12. Significant ration effects occurred in all the fatty acids in immature ova, except in the case of an unidentified fatty acid (Cx). However, the intensity of ration effects on ova were less apparent than in the mature egg yolk. Fatty acids in ova appear to be deposited selectively from adipose tissue during early development. However, as the ova grow bigger, the fatty acid composition begins to bear a resemblance to that of the dietary fat.

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A P P E N D I X

TABLE 2c

ANALYSIS OF VARIANCE FOR FEED CONSUMPTION (GRAMS OF FEED/HEN DAY) BY THREE STRAINS OF HENS FED DIFFERENT RATIONS

Source of Variation	Degree of Freedom	Mean Square
Strain	2	87.8680**
Ration	2	1762.2735**
Period	2	58.2735**
Strain X Ration	4	20.4253
Strain X Period	4	31.9670
Ration X Period	4	178.9175**
Error	8	11.9006
Total	26	

**Significant at $P < 0.01$.

TABLE 3c

ANALYSIS OF VARIANCE FOR EFFICIENCY OF FEED UTILIZATION (GRAMS OF FEED/GRAM OF EGG) OF THREE STRAINS OF HENS FED DIFFERENT RATIONS

Source of Variation	Degree of Freedom	Mean Square
Strain	2	2.2863**
Ration	2	3.3351**
Period	2	0.7499**
Strain X Ration	4	0.4157**
Strain X Period	4	0.1134
Ration X Period	4	0.1376
Error	8	0.0833
Total	26	

**Significant at $P < 0.01$.

TABLE 4c

ANALYSIS OF VARIANCE FOR RATE OF HEN-DAY EGG PRODUCTION BY THREE STRAINS OF HENS FED DIFFERENT RATIONS

Source of Variation	Degree of Freedom	Mean Square
Strain	2	550.1330**
Ration	2	1029.8275**
Period[a]	2	765.0580**
Strain X Ration	4	97.3410**
Strain X Period	4	30.1998*
Ration X Period	4	36.9590*
Error	8	9.0691
Total	26	

[a]Period refers to the duration of experiment.
*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

TABLE 5c

ANALYSIS OF VARIANCE FOR EGG PRODUCTION (GRAMS OF EGG/HEN DAY) FOR THREE STRAINS OF HENS FED DIFFERENT RATIONS

Source of Variation	Degree of Freedom	Mean Square (3 Periods)
Strain	2	168.8704**
Ration	2	688.1275**
Period	2	91.3952**
Strain X Ration	4	26.8443*
Strain X Period	4	15.3843
Ration X Period	4	11.2856
Error	8	6.5658
Total	26	

*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

TABLE 6c

ANALYSIS OF VARIANCE FOR AVERAGE EGG WEIGHT (GRAMS) FOR THREE STRAINS OF HENS FED DIFFERENT RATIONS

Source of Variation	Degree of Freedom	Mean Square
Strain	2	8.3296**
Ration	2	232.3778**
Period	2	106.9737**
Strain X Ration	4	2.9360
Strain X Period	4	0.5929
Ration X Period	4	0.2980
Ration X Strain X Period	8	0.3161
Error	210	2.1605
Total	236	

**Significant at $P < 0.01$.

TABLE 7c

ANALYSIS OF VARIANCE FOR AVERAGE YOLK WEIGHT (GRAMS) FROM THREE STRAINS OF HENS FED DIFFERENT RATIONS

Source of Variation	Degree of Freedom	Mean Square
Strain	2	2.0156*
Ration	2	50.1971**
Period	2	27.5636**
Strain X Ration	4	0.3651
Strain X Period	4	0.1885
Ration X Period	4	0.1707
Ration X Strain X Period	8	0.0702
Error	210	0.4866
Total	236	

*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

TABLE 10b

ANALYSIS OF VARIANCE FOR C_{14} CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	0.0033	0.0125
Ration	2	2	0.1116**	0.8362**
Period	2	1	0.0078**	0.0427**
Strain X Ration	4	4	0.0010	0.0020
Strain X Period	4	2	0.0015	0.0434**
Ration X Period	4	2	0.0020	0.0975**
Ration X Strain X Period	8	4	0.0009	0.0103
Error	210	139	0.0012	0.0043
Total	236	156		

**Significant at P<0.01.

TABLE 11b

ANALYSIS OF VARIANCE FOR C_{16} CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	3.5308**	8.9336**
Ration	2	2	80.8881**	160.4633**
Period	2	1	5.6657**	108.2460**
Strain X Ration	4	4	0.6756	0.5426
Strain X Period	4	2	0.2928	0.0988
Ration X Period	4	2	0.3695	14.5410**
Ration X Strain X Period	8	4	0.6183	0.1850
Error	210	139	0.2885	0.4652
Total	236	156		

**Significant at $P < 0.01$.

TABLE 12b

ANALYSIS OF VARIANCE FOR $C_{16:1}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	0.0002	0.3752
Ration	2	2	9.6265**	34.0355**
Period	2	1	3.4084**	3.6169**
Strain X Ration	4	4	0.2499**	0.1998
Strain X Period	4	2	0.1121**	0.4208
Ration X Period	4	2	0.1702**	2.1213**
Ration X Strain X Period	8	4	0.0734	0.1588
Error	210	139	0.0455	0.1669
Total	236	156		

**Significant at $P < 0.01$.

TABLE 13b

ANALYSIS OF VARIANCE FOR C_{18} CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	0.9828**	0.0539
Ration	2	2	12.2505**	2.1485**
Period	2	1	1.7399**	3.4690**
Strain X Ration	4	4	0.1123	0.1134
Strain X Period	4	2	0.2806*	0.3688
Ration X Period	4	2	1.0630**	0.9272
Ration X Strain X Period	8	4	0.0577	0.1198
Error	210	139	0.1034	0.4652
Total	236	156		

*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

TABLE 14b

ANALYSIS OF VARIANCE FOR $C_{18:1}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	5.8560**	5.7249**
Ration	2	2	92.5385**	407.9990**
Period	2	1	2.1164**	8.2485**
Strain X Ration	4	4	0.6069	3.3489**
Strain X Period	4	2	0.5015	2.4259**
Ration X Period	4	2	3.4496**	31.6445**
Ration X Strain X Period	8	4	0.7623	2.0436
Error	210	139	0.4182	0.9516
Total	236	156		

**Significant at $P < 0.01$.

TABLE 15b

ANALYSIS OF VARIANCE FOR $C_{18:2}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	2.3081**	2.3351
Ration	2	2	1212.5229**	1337.1501**
Period	2	1	0.2885	75.1865*
Strain X Ration	4	4	1.4568**	5.1155
Strain X Period	4	2	0.4212	0.7358
Ration X Period	4	2	0.4713	77.0103**
Ration X Strain X Period	8	4	0.3130	2.0123
Error	210	139	0.2565	6.9362
Total	236	156		

**Significant at $P < 0.01$.

TABLE 16b

ANALYSIS OF VARIANCE FOR $C_{18:3}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	0.0785	6.9048**
Ration	2	2	8.5887**	167.2936**
Period	2	1	0.2154**	55.1950**
Strain X Ration	4	4	0.2719**	5.3795**
Strain X Period	4	2	0.0571	3.9191*
Ration X Period	4	2	0.4287**	44.3046**
Ration X Strain X Period	8	4	0.0938	2.6802*
Error	210	139	0.0538	0.1777
Total	236	156		

*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

TABLE 17b

ANALYSIS OF VARIANCE FOR $C_{22:1}$ CONTENT (AS % OF TOTAL METHYL ESTERS) IN EGG YOLK AND ADIPOSE TISSUE

Source of Variation	Degree of Freedom		Mean Square	
	Egg Yolk	Adipose Tissue	Egg Yolk	Adipose Tissue
Strain	2	2	0.0201**	1.8435**
Ration	2	2	4.9674**	32.5786**
Period	2	1	0.0042**	3.7519**
Strain X Ration	4	4	0.0201**	1.8435**
Strain X Period	4	2	0.0233**	0.4557
Ration X Period	4	2	0.0042**	3.7520**
Ration X Strain X Period	8	4	0.0233**	0.4556
Error	210	139	0.0059	0.1679
Total	236	156		

**Significant at $P < 0.01$.

TABLE 18b

ANALYSIS OF VARIANCE FOR FATTY ACID COMPOSITION (AS % OF TOTAL METHYL ESTERS) OF TOTAL LIPIDS IN GROWING OVA

Source of Variation	Degree of Freedom	Mean Square							
		C_{14}	C_{16}	$C_{16:1}$	C_{18}	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	Cx
Strain	2	0.01	3.19**	0.18	2.45**	1.68	4.61**	0.94	1.63**
Ration	2	0.16**	37.69**	10.86**	17.02**	217.52**	364.32**	12.33**	0.08
Period	2	0.01	0.23	0.36	1.67	1.22	0.59	0.03	0.33
Strain X Ration	4	0.02	0.17	0.54	0.65	4.86**	4.98**	0.50	0.15
Strain X Period	4	0.01	0.30	0.10	0.68	0.33	0.06	0.07	0.24
Ration X Period	4	0.02	0.67	0.20	0.16	0.58	0.68	0.10	0.06
Ration X Strain X Period	8	0.0001	0.41	0.04	0.20	0.44	0.63	0.18	0.10
Error	27	0.013	0.53	0.26	0.53	1.53	1.14	0.68	0.12
Total	53								

**Significant at $P < 0.01$.